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the meteorological magazine

KEW OBSERVATORY BICENTENARY 1769 – 1969

JUNE 1969 No 1163 Vol 98
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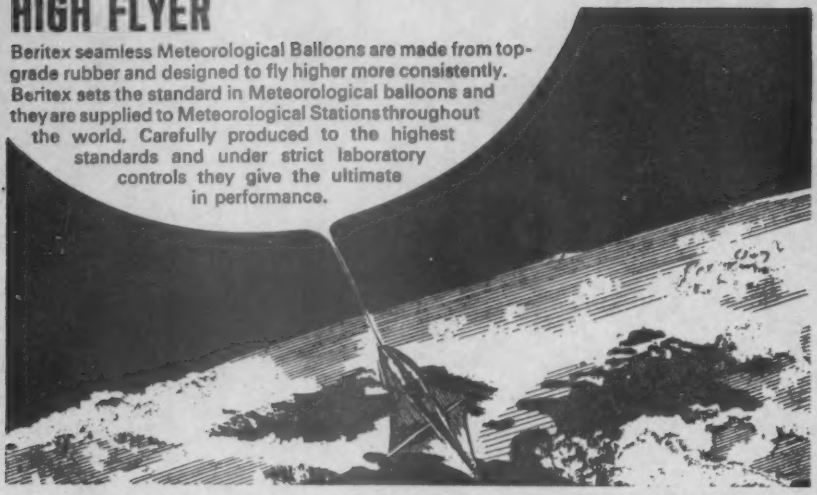

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METEOROLOGICAL OFFICE Met.O.816

THE METEOROLOGICAL MAGAZINE

KEW OBSERVATORY BICENTENARY 1769-1969

Vol. 98, No. 1163, June 1969

FOREWORD

By

THE DIRECTOR-GENERAL OF THE METEOROLOGICAL OFFICE

The story of a scientific institution with two hundred years of achievement behind it is almost bound to be worth the telling. This is especially true of Kew Observatory which will have a lasting place in the history of our subject. Built as an astronomical observatory for King George III, and managed in turn by the British Association, the Royal Society, the National Physical Laboratory and the Meteorological Office, it has provided a quiet, peaceful but stimulating atmosphere in which many famous physicists and meteorologists have done their best work.

Under the leadership of such outstanding men as Welsh, Balfour Stewart, Chree, Whipple (father and son), many of the greatest innovations in meteorology were born or developed there. The Kew-pattern barometer, the meteorograph, radiosonde, alti-electrograph and the early stages of our current rocket and satellite programme, to mention only some of the more important contributions, were landmarks in the development of our science.

Although it continues to be an active centre of investigation, the encroachment of suburbia and the demands of modern research make it unlikely that Kew's future will match its splendid past. It is therefore all the more important that its achievements should be set down for us to read and recognize the foundations on which we build. In paying this modest tribute to the work of our predecessors, we can only marvel at what they achieved with such slender resources, and be grateful for their enthusiasm, ingenuity, and, above all, their patient and dedicated scholarship.

I am most grateful to all those who have contributed to the preparation of this account, and especially to Mr L. Jacobs who conceived the idea and pursued it to a successful conclusion.

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THE 200-YEARS' STORY OF KEW OBSERVATORY

By L. JACOBS

Kew Observatory was built as a Royal Observatory for George III in 1768–69, Sir William Chambers being the architect; it was originally, and rightly, called the King's Observatory at Richmond — the misnomer of 'Kew' came later (sometime between 1812 and 1841) and persists. There is no doubt that Dr Demainbray,[1] a most learned and capable man, who had been tutor to the Royal Family since 1754, had aroused the interest of the King in the forthcoming transit of Venus, due on 3 June 1769. The Observatory was finished in time and George III with the assistance of Dr Demainbray, observed the transit which began soon after 1900 hours. Fortunately the sky cleared soon after 1600 hours at the end of a rainy day with a veer of wind from southerly to westerly, no doubt behind a cold front. It must have been a trying time for the King (Plate I) and his party (Plate II) at Kew and for others awaiting this transit, including the Astronomer Royal, N. Maskelyne, and his six other observers at the Royal Greenwich Observatory. The significance of this transit is discussed in a section on astronomy on p. 163. References are made in the text to the Plates in this issue — Plates I to V illustrate the earlier days of the Observatory, including some of the personalities; Plates VI to IX give illustrations of more recent times.

Dr Demainbray was succeeded, on his death in 1782, by his son the Reverend Demainbray who continued as King's Observer (and for long also acted as royal tutor) until he was retired on pension in 1841 on the closure of the Royal Observatory. S. Rigaud, Dr Demainbray's son-in-law, is recorded as being assistant observer from 1769 until his death in 1814; then his son, S. P. Rigaud, F.R.S. (Savilian Professor at Oxford, first of Geometry and later of Astronomy), took over at the Observatory during the long vacations at Oxford so that the Reverend Demainbray could visit his parish in Wiltshire. This convenient arrangement continued until Rigaud died in 1839.

After this 1841 closure the astronomical and other equipment, including King George's collection of instruments and Queen Charlotte's natural-history collection were dispersed; the 1951 catalogue[2] of the Science Museum gives a good summary of the present whereabouts of most of the material.

Many scientists including E. (later General Sir Edward) Sabine[3] (then General Secretary of the British Association (BA) for the Advancement of Science and later, from 1861 to 1871, President of the Royal Society were anxious that the Observatory should be taken over for experimental work in physics by the Royal Society. At first the Royal Society agreed but soon afterwards refused. However, it was not long before Sabine and others renewed their application, this time to the BA which formally took over the building as a physical and meteorological observatory in May 1842.

It is not clear how F. (later Sir Francis) Ronalds came to take over the position as Honorary Superintendent which he did later in 1842, but he had been well known for many years for his work in atmospheric electricity.[4] A list giving the dates of appointment of King's Observers and Superintendents

up to 1939 accompanies the Plate VI showing the more recent Superintendents. In the present Superintendent's room at Kew there is a memorial tablet[5] giving the names up to 1939, accompanied by the available photographs[6] and a silhouette (Plate IV) of the first King's Observer, Dr Stephen Charles Triboudet Demainbray, which was presented by his great-grandson in 1882. No representation is known to survive of the second Demainbray who died in 1854 at the age of 95.

Initially the management of Kew Observatory came directly under the Council of the BA, but from 1849 a special Kew Committee was appointed. From the beginning this Committee was a very active one, its members not only paying frequent visits to Kew but also providing special equipment and undertaking experiments themselves. Those notably engaged in this work were E. Sabine, J. P. Gassiot (see Plate V) and Warren de la Rue. Both the latter were businessmen (Gassiot was a wine merchant and de la Rue was a member of the family connected with the well-known paper manufacturing business) and were keenly interested in science (both were Fellows of the Royal Society) and published many scientific papers. When, in 1871, the BA was increasingly finding difficulty in financially supporting the Observatory, Gassiot came to the rescue with a donation of £10 000 on condition that the Royal Society took over the management. This was readily agreed and with the interest on this endowment, the increasing revenue from the verification work (see Dr Barrell's article) and a grant from the Meteorological Committee for Kew acting as the Central Observatory (see p. 167) the establishment was put on its feet. (The Royal Society still has a Gassiot Committee which looks after the Gassiot Fund and receives a brief annual report on the work at Kew.)

As discussed in Dr Barrell's article the National Physical Laboratory took over Kew in 1900. Finally the Meteorological Office assumed control from 1 July 1910.

The work at Kew has been very varied over the long years; the following summarized account is divided amongst the subjects of astronomy, general meteorology, upper air work, and geomagnetism, and is followed by a general section. Special topics are discussed in separate articles in this issue and in the July 1969 issue of the *Meteorological Magazine* (reference 34) and also in an issue of *Weather* (reference 18). The article by Dr Scrase is followed by a note by Jacobs to bring up to date the references to instruments, seismology and air pollution.

Astronomy. Transits of Venus across the sun are rare events occurring twice in about a century, the two events being separated by eight years. The first transit of Venus observed in this country was in 1639 and then by only two observers who made no measurements. Astronomers decided that observations of these transits of Venus represented a good opportunity, if sufficient widely spaced measurements were made over the earth, to calculate first the distance of the earth from the sun, later known as the astronomical unit, and then, from this, the general dimensions of the universe. Enthusiasm grew as the 1761 transit time approached and many countries organized expeditions to far parts of the world. The results were disappointing largely because the timing of the transit could not be made exactly owing

to what was known as the 'black drop' causing the spherical shape of Venus to be drawn out in a lingering neck as it passed across the edge of the sun, no doubt due to some atmospheric effect on Venus.

However, a greater effort was made for the 1769 transit and it was hoped that improved telescopes and methods of observations would yield definite results. Again, however, the 'black drop' interfered and this was reported by Demainbray (with little emphasis) in his account of the observations at Kew, and by Maskelyne (with great emphasis) in his account for Greenwich. Demainbray assures us in his manuscript notebook that the observers behind the seven telescopes manned at Kew, other than that looked through by George III, agreed with the royal timing to within one second; however, the timings of the seven observers at Greenwich differed by up to 60½ seconds, for an event which was expected to be timable to within one second, and this kind of range was typical for observations elsewhere.[7] Demainbray received a copy of the Greenwich observations, on 6 June, in a letter from the Astronomer Royal and these observations are recorded in the notebook. However, it is clear that while the Greenwich observations were published,[8] and were used in the subsequent world-wide calculations,[7] the Kew Observatory observations were not published (in fact they never appeared in print until 1926[9]); we may surmise that this is perhaps because Demainbray was puzzled as to the large range of timing in the observations at Greenwich, and merely reassured himself that the Kew Observatory observation (of both external and internal contact) was within this range. The effort of 1769 was notable for the fact that Captain Cook was sent out on his first voyage to the South Seas specifically to observe this transit of Venus and the observations of himself and those sent with him were included in the subsequent calculations.[7] All in all, however, the results of the 1769 world-wide series of measurements were again disappointing although a mean value of the astronomical unit was, of course, obtained. In spite of these disappointments in 1761 and 1769 even greater expeditions set out in 1874 and 1882; the hope was that with improved telescopes the contact observations could be made with much greater precision and, in particular, the use of photography, for the first time, might resolve the difficulties with the 'black drop'; but the results obtained were no better than the older ones. To complete the story of the astronomical unit, later calculations were made from the study of the motion of the near asteroid, Eros.[10] However, in recent years there has been an apparent discrepancy between the Eros results and those derived from measurements by radio astronomers. This discrepancy has now been resolved and an accurate and consistent value has been obtained for the astronomical unit.[11]

On 4 June 1769, the day after the observation of the transit of Venus, an eclipse of the sun was observed at Kew but information is scanty regarding the astronomical work that went on at Kew during the remainder of the Royal period which ended in 1841. Dr Demainbray's grandson recorded in 1881[1] 'His Majesty [George III] frequently attended at the Observatory and procured the best clocks and watches that could be made and placed them in the Observatory under the Doctor's care, so that by daily observations of the sun when passing the meridian, the time was regulated to a second; and for many years the accurate time was taken from the King's Observatory at Kew, for the regulation of the clocks in both Houses of Parliament, at the

House Guards, St. James', and elsewhere, before the accommodation was so well and publicly afforded, as it is in the present day, from the Observatory at Greenwich'. It was clearly through this interest in clocks that John Harrison[12] was able successfully to appeal to George III in 1772 for the conclusion to his long tussle with the Board of Longitude regarding the £20 000 prize for determining longitude; George III personally with Dr Demainbray, supervised the testing of John Harrison's watch at Kew in that year. The original Demainbray manuscript book recording the excellent performance of the watch survives in the collection at King's College Library, London. (The book was mislaid from 1841 to 1960 and thus does not appear in the Science Museum Catalogue.*)

The next period of astronomical work started at Kew in the 1850s when Sir John Herschel, the astronomer, suggested the importance of a daily photographic register of the spots on the sun's disc in order to extend the series of visual observations by Hofrath Schwabe of Dessau who, in 1844, had announced the 11-year sunspot cycle (the discovery was not widely known until Humboldt drew attention to it in 1851). The Kew Committee agreed with the recommendation and a photoheliograph was constructed in 1856. It came into routine use from March 1858 (with various interruptions up to May 1863) under the personal supervision of Warren de la Rue, the chief observer being B. Loewy (who also made pendulum observations — see reference 9 in Dr Barrell's article). In 1860 an expedition headed by Warren de la Rue went to Spain not only with the photoheliograph but also with a portable observatory to photograph the solar eclipse of 18 July 1860. The mission was most successful and it was an important astronomical event in that, for the first time, it was made clear that the flame-like prominences belonged to the sun and were not produced by the deflexion of the sun's light through the valleys of the moon. The actual de la Rue photoheliograph was transferred to Greenwich in 1873 for an experimental period (to 1876). Several new photoheliographs on the Kew pattern were constructed in time for the expeditions in 1874 to observe the transit of Venus. One of these instruments was reserved for Greenwich and the series of solar photographs which began there in 1874 still continues at the Royal Greenwich Observatory, Herstmonceux, Sussex. The original de la Rue photoheliograph is now in the Science Museum. (In 1865 Schwabe presented his original notebooks with drawings of sunspots, from 1825, to Kew for study; this material is now with the Royal Astronomical Society, London, which had presented Schwabe, in 1857, a gold medal for his sunspot periodicity discovery.)

General meteorology. Meteorological observations were made one or more times daily covering the period 1773–1840; these observations are in manuscript books held in King's College Library, London, and have recently been placed on microfilm preparatory to detailed study by the Synoptic Climatology Branch of the Meteorological Office. (Whipple in 1937[13] refers to the observations 'as so unsystematic that they are useless for statistical purposes'; however, this appears to be due to the fact that one book covering the period May 1783 to December 1803 had been mislaid; it was not found until reorganization of the library in 1960. Drummond also commented on this point[14] and did not include consideration of these

older Kew observations in his account of cold winters in 1783–1942.[15]) The thermometers then were placed, as was the custom in the late 18th century, in a window having a northern aspect — the window here was in the north-east corner of the astronomical quadrant room (see Plate VIII). As, at this initial stage, the Observatory had no ground available on which to place instruments the rain-gauge was placed on a pole on the roof — it is clearly visible in the original of the 1792 print reproduced in Plate III, and Ronalds confirms the position in a later report.

When the British Association took over the Royal Observatory, meteorological observations were resumed from November 1842 and with some breaks (mainly in the period 1848–53) have been continuous to this day. The thermometers were removed from the window position and placed in a Glaisher-type screen (similar to that in use at Greenwich) from October 1849; this screen, placed on a pole fixed to the balustrade on top of the steps leading to the entrance (see Plate VIII), had to be turned by hand so that the thermometers were not exposed to the sun. From 1 January 1854 a large screen with double louvers, devised by Welsh (it was the forerunner of the Stevenson screen), was placed just in front of, and readable from, the balustrade, the thermometers being at the same height above the grass (11 feet) as for the Glaisher screen. The Welsh screen continued in use until the north-wall screen with its photothermograph, was adopted in 1867. From 1 January 1969[16] this, in turn, gave way to an aspirated psychrometer at 1.25 metres above the lawn.

The famous Lt Maury wrote in August 1853 (via Sabine), asking for Kew to devise a marine barometer, for general use. Welsh satisfactorily made such a barometer (see Dr Barrell's article) and personally tested it at sea. There was also association with the Meteorological Office from its foundation in 1855, and Admiral FitzRoy wrote to Kew regarding the provision of standard instruments for the newly formed Office.

Much work has been done over the years at Kew on the development of various meteorological instruments and aids to computation. Ronalds's reports from the beginning deal with the photorecording of meteorological (and magnetic) elements (see p. 168). There was further development by Balfour Stewart and the mechanic, Beckley, so that the photobarograph (still in operation) and photothermograph were put into routine use from 1862 and 1867 respectively. (Indeed so much use was made of photographic recording, with a resultant delay in seeing the actual records, that the Meteorological Committee for the year ending 31 March 1914 reports that a considerable number of pen-recording instruments, already available elsewhere, were added to aid the work at Kew.) Welsh, then assistant to Ronalds and later Superintendent himself, invented a slide-rule for humidity (and one for geomagnetic elements) in 1851 and it was a later Superintendent, F. J. W. Whipple, who described the pilot-balloon slide-rule.[17] There is no space here for further remarks on this meteorological work — the general references listed at the end should be consulted. The articles here by Robinson and by Scrase (and by Daws and Lacy[18]) give examples of types of meteorological research and Collingbourne's article (reference 34) describes the radiation investigations. The general layout of the Observatory and its grounds today can be seen from Plate VII.

Kew became the Central Observatory of the Meteorological Office in 1867 and soon after this six other United Kingdom observatories, Falmouth and Stonyhurst in England, Armagh and Valentia in Ireland, and Glasgow and Aberdeen in Scotland, were provided with recording equipment identical to that in use at Kew. Kew was responsible for the general organization of the scheme (Beckley made and installed all the instruments) and the results, including reproduction of the autographic records, were published in the *Quarterly Weather Report;* they still repay study. The Kew meteorological records over the last hundred years or so have been used in many publications, for example by Drummond[15,19] and by Brazell,[20] and are quoted whenever current London weather records are being considered. The Old Deer Park (part of which later became a golf course) continues to surround the Observatory, and the nearest built-up area is some half a mile away. In spite of this there has been in recent years a slow rise of temperature both because of the increase of density of building outside the Park and the increase of heating in such buildings (Craddock[21]). Whereas in 1878 the differences, Kew (north-wall) – Rothamsted (Stevenson screen at an unchanged rural site 20 miles north of Kew), in monthly mean temperature were about 1·2 degF, a value corresponding to the difference in altitude between the stations, they had increased by 1963 to values of between 2·1 and 3·5 degF depending on the month. (Craddock[21] also reviews the differences between north-wall and Stevenson-screen temperatures at Kew in 1879–81, 1923–26 and 1958–60 and concludes there is no significant change over the years. On balance, the daily mean temperature as estimated in each of these periods tends to be about 0·5 degF higher in the north-wall screen).

Upper air. In August 1847 Ronalds and his assistant Birt showed how a stable upper air platform could be obtained by holding a kite with three strings.[22] It was suggested that a pulley on the kite would enable instruments to be raised and lowered readily, but there is no record that any actual measurements were carried out.

Welsh made four personal ascents in a balloon in 1852 (from the well-known Vauxhall Gardens, London) and discussed the results in detail.[23] There is evidence that W. Thomson (later Lord Kelvin) used the data in a paper which gave the first formulation of the dry adiabatic lapse rate and of the saturated adiabatic lapse rate.[24] Much later Sir Napier Shaw reviewed the results.[25] Ten years after Welsh, Glaisher commenced a new series of manned balloon ascents, also under the auspices of the British Association.[26,27]

In the early 1900s W. H. Dines designed and operated cheap light-weight meteorographs which were sent up on unmanned balloons — those that eventually landed safely by parachute being returned to him for analysis of the record. This work was done first at Pyrton Hill from 1907, then at Benson from 1914 and finally was transferred to Kew in 1923. The results were published in the *Observatories' Year Books* up to the cessation of this work in 1939; thereafter radiosondes came into use as is described by Harrison in this issue, thus fulfilling the original 1842 plan by the BA to develop an 'apparatus for telegraphing the indications of meteorological instruments carried up in balloons or by kite, to an observer at the earth's surface'.

Geomagnetism. Sabine,[3] mentioned above in connection with the 1842 BA takeover of Kew, had, as a young army officer in the period 1818–21, been responsible for physical (including geomagnetical and meteorological) and biological observations on two expeditions sent in search of the North-west Passage. Later in the 1820s he went on a further series of journeys and expeditions in which he made similar scientific observations, particularly in relation to geomagnetism and gravity. From 1827 onwards for the rest of his long life (he died in 1883 aged nearly 95) he was almost wholly engaged in scientific investigations. When the Royal Society agreed to the request by Humboldt, in 1836, to set up geomagnetic observatories in different parts of the British Empire, to join in simultaneous observations at set periods at stations already established elsewhere, Sabine was largely responsible for the general arrangements. The observatories at Toronto, St Helena, Cape of Good Hope and Hobarton, Tasmania, began their observations in 1840 (when similar observations also began at the Royal Greenwich Observatory), and it was Sabine who undertook the enormous task of publishing and analysing the results; he went on to collate all the available magnetic data for the world in a series of 'Contributions' to the *Philosophical Transactions of the Royal Society*. Besides his maps of world distribution, the most notable result of Sabine's work was his discovery that the daily range of magnetic declination increases with an increase in the number of sunspots. (This was also pointed out at about the same time by Lamont and Wolf.)

Thus when Ronalds came to Kew Observatory in 1842, Sabine was at hand to encourage him, particularly in the geomagnetic work. So far there was no recording of geomagnetic (or meteorological) elements. The mirror and scale method of increasing deflexions was due to Poggendorff in 1826, and this together with photography, invented in 1839, soon provided the answer to the problem. It seems clear that Ronalds was just ahead of Brooke, who prepared recording equipment for Greenwich in 1847, but Brooke received the Admiralty prize of £500 in 1848 and Ronalds, on protesting, was given a supplementary Government award of £250 the next year (as is recorded in the BA annual report).

The Ronalds photorecording magnetographs, for declination, horizontal and vertical components, were improved over the years by Ronalds and Welsh, and even by Faraday during a visit to the Observatory on 15 November 1850, and came into routine use at Kew from 1857. Sabine analysed the early results. Once these Kew magnetographs had assumed their final form there was a great demand from all parts of the world not only for the supply of such instruments, but also for the training of observers at Kew. The Kew Committee annual reports (see general references) up to about the end of the century give many details of this international co-operation. In November 1869 the Kew Committee reported that Kew had provided magnetographs and in most cases instruction at Kew, for the observatories at 'Java, Coimbra, Lisbon, United States, St. Petersburg, Florence, Stonyhurst, Melbourne, Bombay and Mauritius', and there were others later. There was in this period hardly a scientific expedition organized at home or overseas that did not refer to Kew for advice, training and supply of instruments (and this refers also to instruments other than magnetographs) and for discussion of the results; for example, Livingstone's expeditions to Africa from about 1858,

the Polar Year Fort Rae Expedition of 1882–83 and the Antarctic expeditions from 1899 to 1914.

Scott's history of Kew[28] gives an account of the geomagnetic (and other) work up to 1884; it has a particularly useful bibliography of papers relating to Kew, including those of Sabine. Chree[29] gives a later account,[30] and his 1912 book[31] describes his researches in geomagnetism up to that time. In the early days of magnetic recording funds were not available for a complete reduction of the magnetic traces and analysis was confined to five quiet days per month (selected by the Astronomer Royal up to 1912 and thereafter by the International Centre at de Bilt, Holland). One result of Chree's analyses was to show that these days were atypical particularly in considering secular variations. He extended this work in a special full analysis of all traces in the period 1890–1900 — the results were published in the *Philosophical Transactions of the Royal Society* in 1908, 1910 and 1916. Later work, particularly in the study of the 27-day recurrence tendency of magnetic disturbance, and the survey of Kew data from the start of the recording, is described in a number of *Geophysical Memoirs* of the Meteorological Office by Chree (numbers 17, 22, 30 and 43, 1921–28) and Stagg[32] (numbers 29, 32, 36, 40 and 42, 1926–28) and in a final joint paper.[33] Full publication of the geomagnetic data started from 1911 in the *British Meteorological and Magnetic Year Book* and this was followed, from 1922, by the *Observatories' Year Book*. The records at Kew were disturbed by electric trams and trains from about 1900 to the end of the recording in 1925 but it is worth mentioning that the geomagnetic recording carries on at Eskdalmuir (records from 1908) and Lerwick (records from 1923). The Natural Environment Research Council took over Eskdalemuir from 1968 (but Meteorological Office staff remained for meteorological work and to help, as required, with the seismological and geomagnetic work) and has, in 1969, provided some staff for the geomagnetic work at Lerwick. Kew has continued to be of some help to the other observatories in that the workshop facilities have been used to repair magnetometers and, in 1960–63, to make the required coils for the proton vector magnetometers for the observatories at Eskdalemuir and Lerwick.

General. Looking through the various documents in relation to Kew, one comes across a galaxy of names of famous persons in physics and meteorology who have been connected with the work. A tribute must, however, be paid here to the staff at Kew over the years who faithfully carried out work which, while important, must often have been tedious. Many of their names are recorded in the early annual reports (see general references). Mention is made here of E. Boxall, A. G. W. Howard and R. Relf (see Plate IX) who were all in their fiftieth year of public service when they retired at Kew (in 1941, 1955 and 1967 respectively), and T. W. Baker who retired in 1912 after 52 years' service, all at Kew.

Kew continues today as a full meteorological observatory making extra specialized measurements as required, its main investigational interests now being in relation to radiation[34] and in the study of fair-weather atmospheric electricity.

General references. *The Reports of the British Association for the Advancement of Science* 1842–1871 give statements regarding the work at Kew — from 1851 onwards they include the reports of the Kew Committee; the reports of the latter are continued in the *Proceedings of the Royal Society*, 1872–1900. Following this there are the *Reports of the Observatory Department of the National*

Physical Laboratory 1900–09, and the annual reports of the Meteorological Office from 1910 onwards. *The Observatories' Year Book*, 1922–67, and its predecessor give many details; several have plans and photographs. Howarth gives a general account of the BA days in *The British Association for the Advancement of Science: a retrospect 1831–1921*, published by the Association in 1922.

In the Archives of the Meteorological Office are the manuscript minutes of the Kew Committee 1849–1900, the manuscript Kew diary 28 August 1850–31 October 1851 and many letters and documents from about 1840.

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551.509.9:53:681.2.08

KEW OBSERVATORY AND THE NATIONAL PHYSICAL LABORATORY

By H. BARRELL, C.B.E.
National Physical Laboratory, Teddington, Middlesex.

Introduction. One of the aims of the British Association in taking over Kew Observatory in 1842 was to establish standard instruments for meteorology and geomagnetism there so that other instruments could be brought to Kew for comparison. This type of work began when the famous Regnault provided Kew, early in 1851, with a thermometer which he had calibrated himself; at the same time he arranged the supply of the apparatus for graduating thermometers generally, for the determination of the freezing- and boiling-points of water and for the marking of the divisions by a Perraux machine, and satisfied himself as to the accuracy of the whole equipment. A sub-committee of the main Kew Committee, consisting of Mr Gassiot, Dr Miller and Colonel Sabine supervised the initial installation of the equipment at Kew and reported on 11 April 1851 'that the Observatory may now be considered to possess a standard thermometer with which other thermometers designed to be used as standards may be advantageously compared'. Regnault himself visited the Observatory on 29 July 1851 and the Kew diary mentioned in general references (see page 170) records the useful advice he gave.

The work soon grew and instruments other than those for meteorology and geomagnetism were involved. Barometers and hydrometers (see Plates X and XII) were verified from 1853, magnetic instruments were considered from 1856 and later in the century anemometers, rain-gauges, sunshine recorders, theodolites, sextants, compasses, telescopes and binoculars, lenses, watches and chronometers and a miscellaneous collection including barographs, thermographs, air meters, artificial horizons and rain measures were added in turn. Standard charges were made from the beginning.

Chree[1] gives a concise review of the development of this Kew verification

TABLE I—NUMBERS OF INSTRUMENTS VERIFIED AT KEW DURING 1853–95

Self-recording magnetic instruments	21	Sunshine recorders	15
Magnetometers	117	Theodolites	78
Inclinometers (dip circles)	155	Sextants	3 847
Thermometers (except clinical)	68 727	Compasses	423
Clinical thermometers	183 057	Telescopes	2 731
Mercury barometers	6 673	Binoculars	2 574
Aneroid barometers	1 572	Watches	7 781
Hydrometers	9 430	Chronometers	221
Anemometers	206	Miscellaneous	3 363
Rain-gauges	228	Total 1853–95	291 219

TABLE II—GROWTH OF VERIFICATION WORK AT KEW (1853–95)

Period	Total number of verifications	Average annual number
1853 – 55	4 250	1 417
1856 – 65	8 347	835
1866 – 75	18 587	1 859
1876 – 85	71 756	7 176
1886 – 95	188 279	18 828

service in the individual categories of instruments and Tables I and II here give his analysis for the period 1853–95. Table I shows the total numbers of instruments in the various categories which were verified and Table II the growth of the work. Broadly speaking, the average annual number of verifications remained fairly constant until about 1870 and then started to climb rapidly, mainly because of the expansion of thermometry and especially after the inclusion of tests for clinical thermometers. In fact, clinical thermometers represent 63 per cent, and all other types of thermometers nearly 24 per cent, of the total number of verifications during 1853–95.

There follows a review of some items of the Kew verification service and the allied experimental work and investigations. The selection of items is limited to four categories of instruments — thermometers, barometers, sextants, and watches and chronometers — and a note on some experimental work with pendulums for world-wide gravity surveys is included. The achievements with these particular instruments are characteristic of those made during the years up to the end of the century when, as will be described below, the Observatory became 'the Observatory Department' of the newly formed National Physical Laboratory (NPL).

Thermometers. Following the initial help by Regnault, mentioned above, both calibration and construction of standard thermometers became an important activity at Kew and it is reported that by 1895 over 700 thermometers had been made, of which some 600 were issued to physicists and instrument makers, and also to other observatories, as standards. For instance, reference is made to a Kew standard mercury-in-glass thermometer by W. H. Miller,[2] one of the Commissioners appointed by Parliament to superintend the construction of new national standards of length and mass to replace the standards ruined in the great fire at the Houses of Parliament in 1834. This thermometer, designated *K* and bearing the inscription 'No 43, Kew Observatory, July 1853', was supplied by the Kew Committee and was used to verify other thermometers employed in the work of the Commissioners. It was constructed under the supervision of J. Welsh and was of range 0°C to 100°C divided to 0·2 degC (approximately 1-mm intervals of length upon the stem) and could be read by estimation to 0·1 division. When verified at Kew by a method employed by the Rev. S. Sheepshanks (another Commissioner), it was concluded that the graduation was correct throughout the scale to 0·02 degC.

Balfour Stewart carried out some interesting experiments with an air thermometer which were described in 1863.[3] With the aid of a grant of £150 from the Royal Society he undertook the project to add a third fixed thermometer point — the freezing-point of mercury — to the ice and steam points for the calibration of thermometers. A constant-volume air thermometer was used containing dry air free from carbon dioxide. The result obtained for α (coefficient of increase of pressure of air at constant volume) was expressed in the form $(1 + 180\alpha) = 1{\cdot}367\,28 \pm 0{\cdot}000\,07$, for the range 32°F to 212°F, and the freezing-point of mercury determined by the air thermometer was − 37·93°F. Regnault's value at that date for $(1 + 180\alpha)$ was 1·36657 and the modern value is 1·367 44; the value, − 37·93°F, for the freezing-point of mercury is equivalent to − 38·85°C and the modern value is − 38·862°C — a striking testimony to the accuracy of a determination made at Kew over a century ago.

The earlier mentioned influx of clinical thermometers led to the need to install more sophisticated test equipment than had been provided initially. F. Galton (then a member and later chairman of the Kew Committee) designed apparatus which enabled rapid comparisons of batches of thermometers to be made at any specified temperature between the freezing- and boiling-points of water.[4] The basic techniques thus introduced, using appropriately lagged and stirred water (or other liquid) baths, are much the same as those employed today in testing thermometers. For temperatures below the freezing-point of water, down to 12°F or lower, use was made of freezing mixtures, and minimum thermometers were tested at the freezing-point of mercury, attained with the aid of compressed carbon-dioxide gas. Deep-sea thermometers were tested, mainly for the Admiralty, under pressures equivalent to those attained at great depths, using a hydraulic press installed in 1878 to produce the controlled environment. In the same year the practice was introduced of etching the monogram of the letters K and O

on thermometers which passed the Kew specification of accuracy — an approval mark which was subsequently applied to other categories of satisfactory instruments and became as well known, both nationally and internationally, as the NPL monogram at a later date.

Barometers. The verification of mercury barometers commenced in 1853 and comprised tests of the ordinary patterns then available for use on land and at sea. Aneroid barometers began to be submitted for verification much later, thus accounting for the much lower numbers dealt with in relation to mercury barometers — see Table I. Welsh described in 1856[5] the many attempts he had made earlier to prepare a satisfactory barometer tube of about 1-inch internal diameter, and then to fill it with pure mercury (Plate X). He gives an account of the techniques finally devised to produce standard instruments and also of equipment made for verifying barometers under test against a standard in a variable-pressure receiver. Reference is made in the paper to the lack, in many portable (marine) barometers received for test, of means for adjusting the mercury surface in the cistern to a constant level and of the need, therefore, to determine the correction for 'capacity', or the variation of the mercury level in the cistern corresponding to different heights of the mercury column in the tube. It is stated that this correction may be determined during construction of the barometer so that 'by reducing in the required proportion the lengths of the divisions it (i.e. the variation of zero point) may be allowed for in graduating the scale as has been done in the marine barometers made under the supervision of the Kew Committee by Mr P. Adie of London'. This appears to be the earliest reference to what is still known as the Kew-type barometer, in which the need to adjust the

mercury level in the cistern before taking a reading, as in the Fortin type, is eliminated by the method, outlined above, of using an appropriately contracted scale for reading the height of the mercury column.

G. M. Whipple described, in 1878,[6] some intercomparisons of standard barometers at the Royal Observatory, Greenwich, and at the Kew Observatory, made as a result of some queries from foreign observers as to possible differences between the two standards. Four barometers of the Fortin type from Kew were used as transfer standards and were conveyed by carriage (hence the nickname of such transfer standards as 'hack' barometers) to and fro between Kew and Greenwich for comparisons with the standard barometers at the two stations. Three different sets of comparisons were made and the mean result came out to be: Greenwich – Kew = – 0·000 1 inch (– 0·003 mb).

Watches and chronometers. The rating of watches commenced in 1884 on a system of verification based closely on that used at the Geneva Observatory. Three classes of certificates were issued, namely *A* (the highest), *B* and *C*, according to the severity of the trial for which the watch was entered. The trial of a watch entered for Class *A* occupied 45 days (eight periods of 5 days each and 5 other days in which the watch was not rated); during the test the watch was rated when disposed in different positions and at three different temperatures. The Class *B* test occupied 31 days. The Class *C* tests were discontinued in 1897 because of a lack of demand for them.

Kew had several clocks and chronometers of the observatory type which were used as reference standards and which were checked by frequent observations of both solar and sidereal transits; however, two extra 'mean time' clocks, one being loaned by the Astronomer Royal (it was Dent 2011 and had originally been purchased for the Transit of Venus Expeditions of 1874), were acquired in 1884 for this extra work. On 22 January 1884 the first experiment on the use of the GPO telegraph, as a means of transmitting a time signal from the Royal Observatory, Greenwich, was undertaken, when a direct connection was made between Greenwich Observatory and the Richmond Post Office — two chronometers which were conveyed from Kew Observatory to Richmond Post Office showed, on comparison with the signal, a satisfactory agreement between the times as kept at the two observatories. By 1889, direct telegraphic connection had been established between the two observatories for the regular transmission of time signals; however there were some irregularities in the early years and Kew continued its solar and sidereal transit observations, on occasions, up to 1893. Two burglar-proof (and fire-proof) safes were installed, one for holding the watches while under test at ambient temperatures and the other for tests at either high or low temperatures, using gas heating for the former and ice cooling for the latter. A third rating safe was later obtained, so that temperatures near 40°F, 65°F and 90°F could be continuously maintained the year round.

At the request of watchmakers and others, a system for awarding marks to Class *A* watches was instituted in 1885 to indicate the degree of performance achieved during the rating tests, the marking scheme being similar to that already used at Geneva and Yale observatories. In it the number of marks awarded to a watch that only just succeeded in obtaining a Class *A* certificate

was zero, but to an absolutely perfect watch would be a 100 made up as follows : 40 for a complete absence of variation of daily rate, 40 for absolute freedom from change of rate with change of position and 20 for perfect compensation for effects of alteration of temperature. From 1890 onwards, watches receiving 80 marks and upwards had the legend 'especially good' added to the certificate. The highest mark achieved by any watch entered for the Class *A* certificate at Kew was 96·1 in 1912, the year during which the rating of watches and chronometers was transferred to the NPL, Teddington.

Rating tests were extended to marine chronometers in 1886. For these instruments the trial occupied 35 days (five periods of 6 days each plus 1 day at the commencement of each period when the chronometer was not rated). The tests were made in a symmetrical fashion at three different temperatures. Two classes, *A* and *B*, of certificates were issued according to the quality of performance achieved; the Class *B* certificate was abolished in 1905.

Sextants. In 1862 a simple means of testing the accuracy of the angular scales of sextants was set up by F. Galton in the Old Deer Park, near the Observatory. On each of four pillars, erected along a circular arc of ½-mile radius and subtending angles of 20°, 60° and 40° at the centre of the arc, was fixed a small mirror. At the centre, beside the observer and the sextant under test, were two mirrors for reflecting light from the sun towards two of the four distant mirrors. This light entered the telescope of the sextant when the mirrors at the centre were suitably inclined. An assistant beside the observer altered continuously the inclination of these mirrors to compensate for the sun's motion and also made the change from one combination of mirrors to another. Observations were made every 20° from 20° to 120° and the zero error was deduced by calculation. The angular distances between the mirrors fixed to the pillars were determined by means of a theodolite. Class *A, B* and *C* certificates were issued.

This original outdoor equipment, inconvenient in many ways, particularly because the tests could only be made during periods of steady sunshine, was replaced in 1866 by a more elaborate apparatus designed by T. Cooke, an optician; it is described by Balfour Stewart[7] and was set up in the basement of the Observatory. The NPL built a similar equipment in 1912, to accommodate the testing of sextants when the Kew verification work was being transferred to Teddington, and a photograph of this is shown in Plate XI. The series of double-collimator units is very similar to that of the original apparatus at Kew (though the illumination is by small electric lamps instead of candles) and graticules with suitable matching patterns of transparent lines on an opaque background replaced the former crosswires; similar modifications had indeed already been introduced into the Kew apparatus before the work was transferred to Teddington. In the NPL equipment there are 13 double-collimator units arranged to subtend angles differing by 10°, 15° and 20°. The spacings provide angles in 5° steps from 0° to 180°, with a few exceptions, and many angles are duplicated. No provision was made originally at Kew to determine the errors of the dark shades used to screen the observer's eyes when the sextant is directed to the sun or moon. Errors occur because of non-parallelism and distortion of the faces of these

dark glasses, and also because of flatness errors in the surfaces of the sextant mirrors. Apparatus for examining these optical components of sextants was set up at Kew at the request of the sextant makers, and was described by G. M. Whipple.[8]

Pendulums for gravity surveys. Experiments were made at Kew in 1865 to determine the constants of two 'invariable' pendulums which were to be used for geodetic purposes in the Indian Trigonometrical Survey. A paper[9] gives a full account of the work, describing how the number of vibrations made by each of the two pendulums in a mean solar day was ascertained in an evacuated enclosure. Mention is made in the Kew Committee Report for 1864–65 of Colonel (later General) Walker and Captain Basevi, who received instruction at Kew in the techniques of 'swinging' pendulums for the gravity survey of India. The results obtained at Kew served as the control and basis of reference for the subsequent work.

From time to time similar experiments with pendulums were undertaken at Kew and an interesting account of some of these was given by General Walker in 1890.[10] The pendulum operations described were undertaken to determine the gravity connection between the Kew Observatory and the Royal Observatory, Greenwich, in order to establish the relationship between the series of pendulum observations made during the Indian Survey and other series, made in different parts of the world, which had been based on Greenwich as the reference station. The paper gives details of all the pendulums and experimental methods used.

Origins of the National Physical Laboratory. At the Norwich meeting of the British Association in 1868 Colonel Strange read a paper entitled 'On the necessity for state intervention to secure the progress of physical science'. To the Association, with the experience of its Kew Committee in managing the Observatory on a restricted budget and with the firm conviction that the work done at Kew was of considerable benefit to science and industry, this idea of governmental support for a purpose which had long been the objective of the Committee was evidently attractive. Further references to the subject were made at subsequent meetings of the Association, notably at Glasgow in 1871 by Lord Kelvin and at Cardiff in 1891 by Sir Oliver Lodge, the latter thereby arousing the interest of the Association's Secretary, Sir Douglas Galton.

Meanwhile, during the period 1883–87, the Physikalische technische Reichsanstalt had been established at Charlottenburg, near Berlin, as the national standards laboratory, the first of its kind set up under state auspices to assist national science and industry. In his presidential address to the Association at its Ipswich meeting in 1895, Galton, who had visited the German laboratory earlier in that year, urged the importance of establishing a similar laboratory in this country. A committee was appointed by the Association, with Galton as chairman and Lord Rayleigh (the third Baron) as another of its 14 members, to consider the establishment of a National Physical Laboratory for the more accurate determination of physical constants and for other quantitative research. This committee reported to the Liverpool

meeting of the Association in 1896. It recommended that the Royal Society be responsible for the definition of the proposed Laboratory's functions and for its management; estimates were made of the monies required for initial building and equipment and for annual maintenance of its work.

In 1897 the Government set up a committee of inquiry into the matter, with Rayleigh as chairman; the Chairman of the Kew Committee, F. Galton, and the Superintendent of Kew Observatory, C. Chree, gave evidence before this committee, which visited the Observatory early in 1898. The main conclusion of the report of the committee, made to the Lords Commissioners of Her Majesty's Treasury in July 1898, was that a National Physical Laboratory should be established under the control of the Royal Society and the four recommendations emanating from this conclusion were accepted by the Government. Of these four recommendations, it is germane to quote the first two :

(i) That a public institution should be founded for standardizing and verifying instruments, for testing materials and for the determination of physical constants.

(ii) That the institution should be established by extending the Kew Observatory in the Old Deer Park, Richmond, and that the scheme should include the improvement of the existing buildings and the erection of new buildings at some distance from the present Observatory.

The Royal Society agreed to co-operate in carrying the recommendations into effect, with financial aid voted by Parliament, and drew up a scheme for the organization of the Laboratory, which was officially approved. In accordance with this scheme the Kew Observatory was to be incorporated with the National Physical Laboratory and to become part of its organization from 1 January 1900, on which date the Kew Committee would cease to exist. The work at Kew was to proceed as hitherto and to be carried on by the existing staff of 19.

The scheme of organization included the founding of an Executive Committee to be the authority having the immediate management of the new Laboratory, and six members of the Kew Committee were nominated to its membership. The scheme also provided for the appointment of a Director who, subject to the authority of the Executive Committee, was to have sole control and direction of the staff of the Laboratory and of the work done within it. Dr R. T. (later Sir Richard) Glazebrook was appointed to the post as from 1 January 1900.

In accordance with the second recommendation of Rayleigh's Committee, a site of about 15 acres in the north-east corner of the Old Deer Park, Richmond, was chosen; however, difficulties arose because of objections of local inhabitants to siting the Laboratory in the Park; a question was asked in Parliament and a deputation of persons was sent to lay the reasons for objection before the Financial Secretary to the Treasury. Although the Executive Committee were unfavourable at first to considering other sites, agreement was eventually achieved, late in 1900, on Bushy House with its grounds, on the edge of Bushy Park, Teddington, as the acceptable alternative. Thus the NPL had its beginning, the British Association and the Royal Society being its progenitors and the Kew Observatory constituting 'the Observatory Department' of the new structure.

The Observatory Department of the NPL. The published annual *Reports of the NPL* for the years 1900 and 1901 relate entirely to the work done at Kew; thereafter, until 1909, the yearly account of the work at Kew Observatory appears in the Observatory Department part of the annual *Report of the NPL*. Table III, taken from the annual *Report of the NPL* for 1910 gives a continuation of the story of the verification work as shown by Tables I and II. It can be deduced from Table III that no less than 673 200 instruments had been tested since 1880. Information from the annual *Reports of the NPL* for 1911 and 1912 show that a further 76 770 instruments were tested at Kew during these years. An estimated figure of 58 700 for the period 1853–80 can be derived from the information given in Table II, so it would appear that, from the main start of the verification of instruments at Kew in 1853, the grand total is about 809 000.

TABLE III—GROWTH OF VERIFICATION WORK AT KEW SINCE 1880

Class of instrument	Average number of instruments tested per annum during each decade		
	1881–90	1891–1900	1901–10
Barometers			
Aneroid	81	124	168
Mercury	151	211	261
Hydrometers	390	323	500
Thermometers			
Clinical	8 462	16 502	19 909
Meteorological	1 801	2 823	3 940
Binoculars	68	475	1 054
Telescopes	26	632	3 601
Sextants	139	613	1 078
Watches	302	737	386
Marine chronometers	5	48	75
Inclinometers	6	6	10
Unifilar magnetometers	4	4	7
Others	1081	583	734
All instruments	**12 516**	**23 081**	**31 723**

In the Observatory Department period there was interesting work done on the comparison of the scale of the Kew standard mercury-in-glass thermometers with the hydrogen scale,[11] in which it was concluded that the departure of the Kew scale from the international hydrogen scale was very small at all temperatures within the range investigated, 0°C to 100°C. In 1901 an account was published[12] of the work on platinum resistance thermometers commenced at Kew in 1895; detailed examination was made of the various sources of error found in platinum resistance thermometers and the associated Callendar-Griffiths resistance bridge, the results obtained representing a notable contribution to the development and improvement of resistance thermometry at that date.

Concluding remarks. To conclude this NPL tribute to the achievements of the instrument verification service initiated at Kew over a century ago, it is of interest to remark very briefly on the history of this service since its transfer to Teddington in 1912–13. At that date the service became the responsibility of three sections of the Physics Department, namely Heat (thermometers), Metrology (barometers, aneroids, hydrometers and also watches and chronometers), and Optics (optical instruments). These sections

later became organized into separate Divisions of the Laboratory as a consequence of their increased responsibilities for research in the various specialist aspects of measurement science and to meet the corresponding development of diverse new requirements for verifications. In 1949, the NPL Test House was founded to relieve the Divisions of a major proportion of their routine and repetitive verification work, bringing it within a suitably planned unit to provide a comprehensive service for science and industry.

More recently it has become the policy of the Laboratory to pass certain categories of verification work to external organizations which are considered to have suitable staff and facilities to undertake the service. The first such transfer, of clinical thermometers, was to the British Standard Institution's Test House (Hemel Hempstead), which later undertook the verification of certain classes of meteorological and industrial thermometers, as well as hydrometers and other instruments. Previously, the average annual number of thermometers tested at Teddington was around 500 000, for the clinical type, and about 8000 for other types. Binoculars, telescopes and sextants are now inspected in laboratories within the Admiralty establishment, for which the major proportion of such instruments had been verified in the past at Kew and Teddington. The service for rating watches and chronometers is at present being maintained at the NPL; the Kew Class *A* test for watches, however, was discontinued in 1951, together with the system of allocating marks for superior performance, and was replaced by a Craftsmanship test designed to encourage the re-establishment of watch craftsmanship in this country.

The British Calibration Service set up in 1966 with headquarters in the Ministry of Technology will, in due course, considerably modify the organization of the instrument verification service in this country. Already several laboratories have been officially approved to provide a service for the certification of various categories of measuring instruments in return for fees. Laboratories in industry, research associations, universities or other educational institutions and government establishments may apply for approval. The NPL is associated with the scheme in an advisory capacity and participates in the procedure for the approval of laboratories. The Laboratory also provides, through its recently established Metrology Centre, the facilities for ensuring that the bases of reference for measurement in the approved laboratories are related to the national standards maintained at the NPL.

Acknowledgements are made to: Mr L. Jacobs, Meteorological Office, for much assistance in the preparation of this article; Cdr A. G. Thoday, Science Museum, for providing the illustration of Kew standard barometers (Plate X); and to Mr D. J. Bryden, Department of Technology, Royal Scottish Museum, for providing the illustration of hydrometers (Plate XII).

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551.5(09):551.501.9

SOME REMINISCENCES OF KEW OBSERVATORY IN THE TWENTIES

By F. J. SCRASE, O.B.E.[1]

When I first joined the staff of Kew Observatory in 1920 as a Junior Professional Assistant (at a basic salary of £175 per annum plus a cost-of-living bonus which just doubled this figure), my first impression was that very little could have changed there since the time of George III, for whom the Observatory was built. Some reconstruction of the interior of the building had, in fact, taken place in 1913 soon after the section of the National Physical Laboratory (NPL) which had tested watches, thermometers, compasses and sextants there since 1900, was transferred to its permanent home at Teddington. The facilities for experimental work at the Observatory, however, compared unfavourably with those I had enjoyed at the Cavendish Laboratory under the guidance of J. J. Thomson, E. Rutherford and C. T. R. Wilson. The place had more the air of a rather musty museum with a large number of instruments of historic interest, and some jars of Queen Charlotte's natural-history collection on view in the glass-fronted cabinets in the octagonal North Hall where one entered the Observatory. Some armchairs, used by the senior staff, had probably survived since George III's time.

Inside the dome there was the photoheliograph installed in 1856 for sunspot observations, and on top of the dome was the massive Robinson-Beckley cup anemograph of about the same date and still working in 1920. In the Clinical House, so-called because it was where clinical thermometers used to be tested, the water-dropper electrograph set up in 1861 under the personal supervision of William Thomson (later Lord Kelvin) was still in operation. Other historic instruments continuing to be used in 1920, included John Welsh's standard

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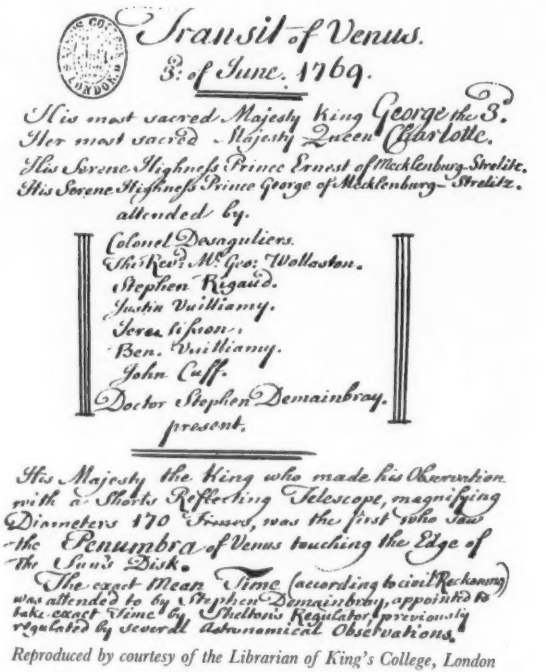
PLATE I—PORTRAIT OF GEORGE III, FOUNDER OF KEW OBSERVATORY

King George III founded the Observatory (built 1768–69) primarily for the observation of the transit of Venus, which occurred on 3 June 1769. The portrait shows the king at about 1767 and now hangs in the National Portrait Gallery, London. See page 162.



Transit of Venus.
3: of June. 1769.

His most sacred Majesty King George the 3.
Her most sacred Majesty Queen Charlotte.
His Serene Highness Prince Ernest of Mecklenburg-Strelitz.
His Serene Highness Prince George of Mecklenburg-Strelitz.
attended by.

Colonel Desaguliers.
The Revd. Mr. Geo: Wollaston.
Stephen Rigaud.
Justin Vuilliamy.
Jere. Sisson.
Ben. Vuilliamy.
John Cuff.
Doctor Stephen Demainbray.
present.

His Majesty the King who made his Observation with a 7 Feets Reflecting Telescope, magnifying Diameters 170 Times, was the first who saw the Penumbra of Venus touching the Edge of the Suns Disk.

The exact Mean Time (according to civil Reckoning) was attended to by Stephen Demainbray, appointed to take exact Time by Thelton's Regulator, previously regulated by several Astronomical Observations.

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PLATE II—THE FIRST OBSERVATION FROM KEW OBSERVATORY — THE TRANSIT OF VENUS ON 3 JUNE 1769

The account is by Dr Demainbray and page 1 shown here begins with a list of those present. The telescope and clock referred to are now in the museum of the planetarium adjacent to Armagh Observatory, Northern Ireland. The manuscript book (MS/1) is in the Library of King's College, London. See page 162.

To face page 180

Reproduced by courtesy of L. Jacobs

PLATE III—THE OBSERVATORY IN THE LATE 18TH CENTURY VIEWED FROM ABOUT THE SOUTH-WEST

The plate is reproduced from a print ($8\frac{1}{2} \times 7$ inches), in the possession of L. Jacobs, which was published in 1792 by T. Cadell, Strand, London, and entitled 'The Observatory in Richmond Gardens'. The main telescopes were in the dome, the roof of which could be opened and moved. The facing room on the west, with four long windows visible, was used for routine transit observations, while the corresponding room on the far side of the building was used for quadrant observations. Not visible are tall obelisks in the Park still existing, one 300 yards away to mark north from the centre of the Observatory and two, 900 yards away, marking south from the transit and quadrant rooms respectively. As no ground was available outside for instrumental work until about 1856, the rain-gauge was placed on a pole near the southern edge of the flat part of the roof — it is clearly visible in the original print. The Observatory is built on an artificial mound. See page 166.

Photograph of the silhouette at Kew Observatory by courtesy of R. K. Pilsbury

PLATE IV—SILHOUETTE OF DR STEPHEN CHARLES TRIBOUDET DEMAINBRAY

He was the first King's Observer at Kew Observatory, 1769–1782. The original silhouette is at Kew Observatory to which it was presented by his great-grandson in 1882. See page 163.

PLATE V—THE OBSERVATORY TODAY — A CORNER OF THE ENTRANCE HALL

From left to right are the busts of S. P. Rigaud (1774–1839), E. Sabine (1788–1883), and J. P. Gassiot (1797–1877). See page 163.

PLATE VI—THE SUPERINTENDENTS AT KEW 1947–1969

The photograph was taken at Bracknell on 22 July 1968. From left to right the superintendents with their dates of appointment are: 1947, George David Robinson; 1957, Kenneth Hope Stewart; 1960, Robert Henry Collingbourne; 1966, Richard Alexander Hamilton; 1968, Stanley Gershon Crawford.

A composite photograph of superintendents 1842–1939 is given in the *Meteorological Magazine* for July 1962, and in the issue for November 1954 there is a description of a memorial tablet at the Observatory giving a list of King's Observers and superintendents up to 1939 and their dates of appointment.

King's Observers :

1769 Stephen Charles Triboudet Demainbray
1782 Stephen George Francis Triboudet Demainbray

Superintendents :

1842 Sir Francis Ronalds, F.R.S.
1852 John Welsh, F.R.S.
1859 Balfour Stewart, F.R.S.
1871 Samuel Jeffery
1876 George Mathews Whipple
1893 Charles Chree, F.R.S.
1925 Francis John Welsh Whipple
1939 James Martin Stagg
1939 Sir George Simpson, F.R.S.

Sir George Simpson (who had retired from the post of Director of the Meteorological Office on 2 September 1938 but had voluntarily resumed duty at Kew from September 1939) continued as Superintendent until 1946, when J. M. Stagg returned. The next Superintendent was G. D. Robinson, in 1947. See page 163.

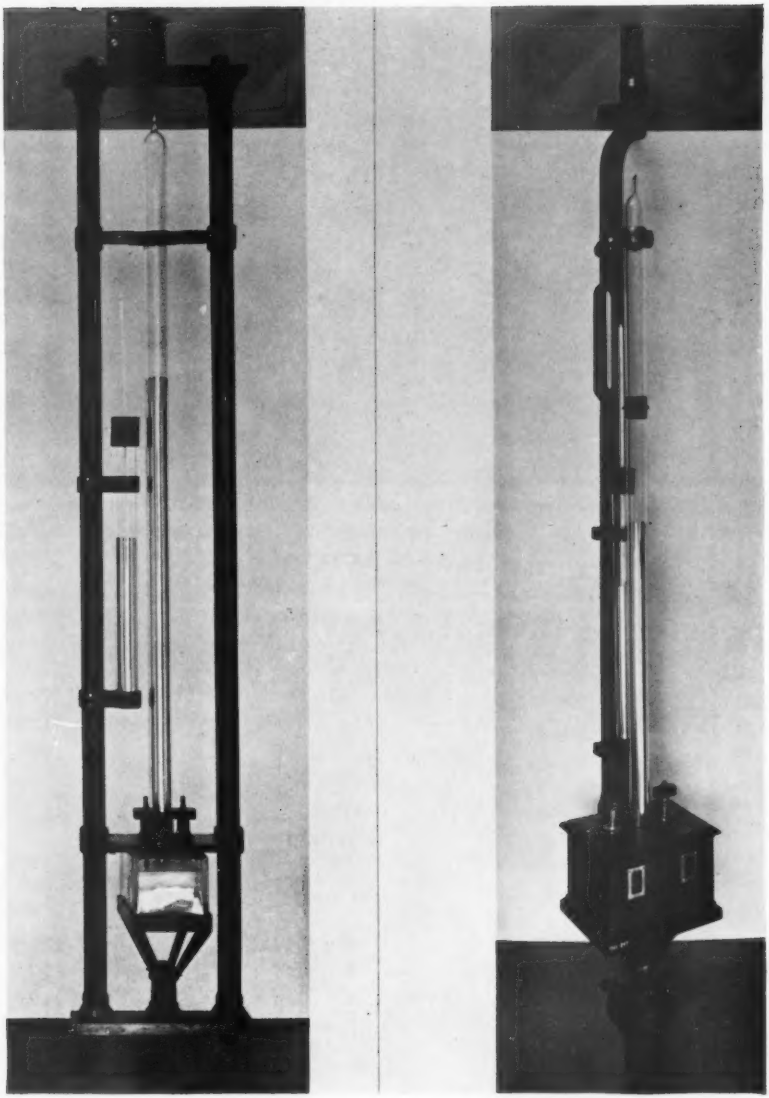
PLATE VII—AN AERIAL PHOTOGRAPH OF THE OBSERVATORY

This view of the Observatory shows part of its six acres of grounds — and was taken in 1965 from the south at 500 feet. A plan and full details of the instrumental equipment are also given in the 1965 *Observatories' Year Book;* the main changes up to 1969 are the addition of several different types of evaporimeters in the right foreground and the cessation of the tethered balloon work. The Observatory itself is about 30 feet north–south and about 50 feet east–west and the head of the pressure-tube anemograph, on the top of the dome, is at about 80 feet above the general ground level. The northern obelisk (see caption to Plate III) is some 50 yards beyond the edge of the grass line to the north — many of the trees have now been cleared. See page 166.

PLATE VIII—THE OBSERVATORY TODAY — VIEWED FROM THE NORTH
The ground-floor window to the left just above the balustrade is where the thermometers were exposed from January 1773 to October 1849; then a Glaisher screen was erected on top of the balustrade and this was replaced from 1 January 1854, by a Welsh (Kew) screen near the same place. The north-wall screen, seen on the right, came into use from October 1867 and was, in its turn, replaced by an aspirated psychrometer in the middle of the lawn from 1 January 1969 (see *Meteorological Magazine* for January 1969). The ground-floor window on the west side nearest to the north-wall screen is the site of the water-dropper photo-electrograph installed by W. Thomson (later Lord Kelvin) in 1861 (see note on page 184).

Photograph by courtesy of B. Shardlow

PLATE IX—THE PRESENTATION OF THE IMPERIAL SERVICE MEDAL TO MR R. RELF
The Director-General of the Meteorological Office (Dr B. J. Mason, F.R.S.) is shown with Mr and Mrs R. Relf at Bracknell on 18 December 1967, on the occasion of the presentation. Mr Relf retired from service at Kew, from April 1918, in July 1967; he was, from 1935, resident caretaker and his wife was resident housekeeper; in the 30 years up to 1965 Mr Relf's duties included 'such participation in the routine observations as the Superintendent may direct', and these observations were mostly made in the early morning, at night and over weekends. See page 169.



Reproduced by courtesy of the Science Museum, London

PLATE X—EARLY KEW STANDARD BAROMETERS

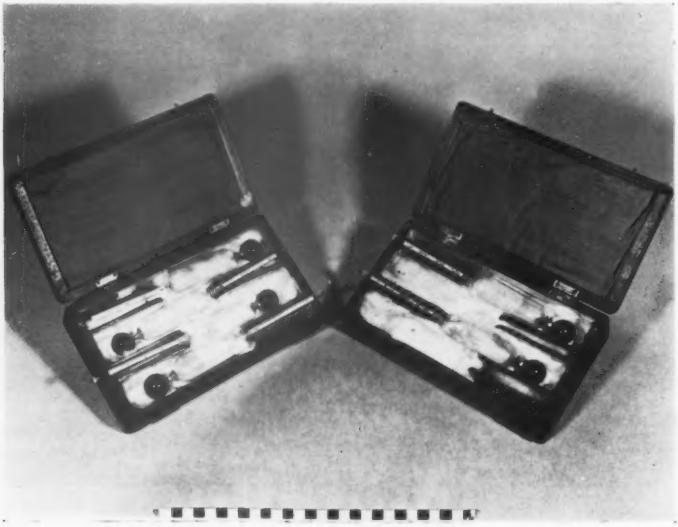
The barometer on the left was constructed in 1855 (Welsh) and the one on the right in 1860 (Stewart and Beckley following Welsh). The instruments were in use at Kew Observatory until 1953, then came into the custody of the National Physical Laboratory until 1966 and are now on permanent loan to the Science Museum. See pages 171 and 181.

To face page 181

Reproduced by courtesy of the National Physical Laboratory, Teddington, Middlesex

PLATE XI—EQUIPMENT USED AT THE NATIONAL PHYSICAL LABORATORY FOR VERIFYING SEXTANTS

The design is based on that of the equipment set up at Kew in 1866. See page 175.



Reproduced by courtesy of the Director, Royal Scottish Museum, Edinburgh

PLATE XII—TWO SETS OF HYDROMETERS

These were made between 1854 and 1857, for the Admiralty or the Board of Trade, and are now in the Department of Technology, Royal Scottish Museum, Edinburgh. They were for use by naval and merchant vessels for measuring the specific gravity of sea water. The set on the right (two missing) was verified at Kew in July 1857. See page 171.

barometers with one-inch tubes (see Plate X), the photographic recording barometer, thermometers and magnetometers, all of which had been in operation some 60 years or more. Time signals for checking the Observatory standard clock were obtained by means of a Post Office telegraphic needle.

In 1920 the Superintendent was Dr Charles Chree, F.R.S. He had been appointed in 1893 and had established a world-wide reputation as an authority on terrestrial magnetism;[2] under his guidance the Observatory had attained a foremost position among the magnetic observatories of the world. He delighted in teaching new members of his staff and many workers from all parts of the world, the technique of magnetic observations and computations. His method of standardizing records of potential gradient led to Kew having a longer series of reliable observations of this element than any other observatory.[3,4] Chree's needs for his own (mainly theoretical) researches were very modest and very little modern laboratory equipment was provided for experimental work. When G. C. (later Sir George) Simpson visited the Observatory soon after becoming Director of the Meteorological Office in 1920, he said he thought the laboratory facilities should be brought up to date and asked Chree to have a list of requirements prepared for this purpose. Simpson recorded later[2] that Chree's short list included four rings for a retort stand and a nest of four beakers. Chree scorned the use of a typewriter and wrote all his official letters in manuscript; duplicates were made on an old copying press.

One member of the staff in 1920 had been at the Observatory even longer than Chree. This was E. Boxall who was in charge of the computing room where data for the *Geophysical Journal*, precursor of the *Observatories' Year Book*, were prepared. Boxall recollected Chree's predecessor, G. M. Whipple,[5] who had started as a boy at the Observatory in 1858, and when the Superintendent used to wear a frock coat and top hat and summon his staff back to work after their lunch-break by blowing a whistle on the front steps. Another 'old-timer' was B. Francis who was nominally the librarian and also acted as guide to the numerous visitors. His main interests, however, were phrenology and spiritualism. He pursued the latter to the extent of holding seances at the Observatory until someone discovered that objects which materialized during the seances were concealed in convenient places beforehand.

On the professional staff in 1920 were C. D. Stewart, who later became head of the meteorological service of the Federated Malay States, R. E. Watson and C. H. Kellett. Watson worked on Ångström pyrheliometer standardization,[6] and later on comparison of the air–earth current at a height of 1 m and at ground level.[7] For the latter measurement he crouched in a very small hole in the ground covered by a metal sheet. It was not until 10 years later that the first underground laboratory was built.[8] Kellett was Resident Observer and subsequently went to Eskdalemuir Observatory, but died at an early age.

Most of my first year at Kew was spent in learning the observational techniques of terrestrial magnetism, atmospheric electricity and meteorology. Amongst other things I learned how to replace broken crosswires of instrument telescopes by spider web. I was later to find out what a great nuisance spider's

webs could be in atmospheric electrical work, in causing breakdown of insulation when moisture condensed on them. The only investigation to which Chree directed me was to determine the errors, due to self-heating, of the Callendar electrical resistance thermograph, an elegant instrument incorporating a self-balancing and recording Wheatstone bridge. It had been installed at the suggestion of Sir Napier Shaw some years earlier in the hope of its replacing the photographic method of recording temperatures of the large wet- and dry-bulb mercury thermometers which had been in use since 1867. Alas, the photographic method proved the more satisfactory in 1920 and, in fact, continued in use until the end of 1968.

I was fortunate in being allowed time off from my duties at Kew to attend the first course of lectures at the School of Meteorology, which was established at Imperial College in 1920 under Sir Napier Shaw, the first Professor of Meteorology in this country. In addition to Sir Napier's lectures on general and synoptic aspects of the subject, Captain (later Sir David) Brunt gave a course on physical and dynamical meteorology, which subsequently formed the basis of his well-known textbook.

It was not until I returned to Kew in 1926, after five years at Porton, by which time Dr F. J. W. Whipple had become Superintendent, that I started an interesting and enjoyable period of eleven years geophysical research. Whipple had close family connections with the Observatory, for not only had his father been Superintendent from 1876 to 1893, but his grandfather was Robert Beckley who had been assistant to earlier Superintendents John Welsh and Balfour Stewart. Whipple gave his staff every encouragement to pursue original work and had no hesitation in asking for the necessary equipment. His own interests covered a wide field, but he is best remembered for his work on the propagation of sound waves from gunfire and explosions,[9] and his determination of the temperature structure of the atmosphere at heights beyond the reach of sounding balloons.[10] One of his outside interests was the excavation of part of the Observatory paddock to reveal the foundations of the Carthusian priory founded by Henry V in 1414.

By 1926 all the geomagnetic work, which for some years had suffered disturbance by the electrification of the nearby railway, had been transferred to Eskdalemuir Observatory[11] and the Galitzin seismographs were brought from that Observatory to Kew,[12] On my return I took over the seismological work from J. M. Stagg and, with the help of the German translation of Prince Galitzin's classic textbook on the subject, I was soon involved in the complicated business of calibrating the instruments.[13] When I came to study the records I was mystified by the occurrence from time to time of large isolated pulses which did not appear to be due to earth tremors. The seismograph pendulums were protected from draughts by large metal cases, but, at first, removal of these showed nothing untoward. Eventually I found that the pulses were caused by earwigs jumping or falling on the pendulums, and while the cases were being removed they scuttled under the bases of the instruments. The remedy was to seal the edges of the cases with grease.

Analysis of the records of earthquakes for the *Kew Seismological Bulletin* and the *International Seismological Summary* soon brought me into contact with H. H. Turner, Savilian Professor of Astronomy at Oxford, who was responsible for

the Summary, and with H. (later Sir Harold) Jeffreys at Cambridge. With their valuable help and the encouragement I received from Whipple, I was led to the study of deep-focus earthquakes[14] and the recognition of the reflected waves associated with them.[15] After a few years I handed over the seismological work to A. W. Lee[16] who concentrated on the study of microseisms and published some important papers on the subject.[17–20]

I took over the investigation of air–earth current from R. E. Watson and, in the course of the next few years, went on to various aspects of atmospheric electricity.[8,21–26] When, as an undergraduate, I attended C. T. R. Wilson's lectures on the subject, little did I think that it would ever provide me with a full-time job. Atmospheric electricity had a very long history at the Observatory, having started in 1843 when F. (later Sir Francis) Ronalds measured the electric potential with a lantern collector above the dome, using a straw electrometer.[8] By the time I came on the scene we had at least advanced to the gold leaf of the Wilson 'Universal Portable Electrometer', and very soon substituted that excellent little instrument, the Lindemann electrometer, in this equipment. My atmospheric electrical work culminated in the collaboration with Sir George Simpson to develop the alti-electrograph for use on sounding balloons to detect the electric fields in and around thunderstorms.[25]

In 1920 a good deal of attention had begun to be given to atmospheric pollution, following the setting up of an Advisory Committee on the subject under the chairmanship of Sir Napier Shaw. An automatic air-filter, invented by J. S. Owens, was installed at the Observatory. Owens also introduced his portable dust-counter which worked on the impaction principle. Some years later I used this instrument to investigate the dust content at various levels in the huge airship hangar at Cardington, where the ill-fated R101 was being built. It was thought that the presence of dust was causing difficulty in joining the gold-beater's skin used in making the gas bags. I became interested in atmospheric aerosols generally, and after resurrecting an old Aitken condensation nucleus counter, began to investigate the effect of dust and nuclei, charged and uncharged, on the electrical conductivity of the air.[26] H. L. Wright continued the work on aerosols but concentrated more on their effect on visibility.[27–30]

Many visitors were attracted to Kew Observatory; they ranged from parties of school children to the heads of geophysical observatories and meteorological services all over the world. There were also frequent training courses for meteorological observers. The annual meetings of the Gassiot Committee of the Royal Society often took place at the Observatory. Its task was to administer the Trust set up by J. P. Gassiot in 1871 for the purpose of assisting magnetic and meteorological observations with self-recording instruments, primarily at Kew Observatory. In the early twenties the chairman was Sir Joseph Thomson. The staff used to watch with great interest the arrival of the eminent scientists attending the meeting, especially Sydney Chapman, who could be seen speeding up the Observatory track on what appeared to be a racing bicycle. It was interesting to read in *The Times* of 29 July 1968, that although more than 80 years of age he was still riding a bicycle and even swimming half a mile a day; moreover, long after retirement

from his Oxford Professorship, he is still at work at the University of Alaska and at the U.S. National Center for Atmospheric Research at Boulder, Colorado.

Before the existence of London/Heathrow Airport and the building of the bypass across the Old Deer Park, life at Kew Observatory was very quiet and peaceful. Behind the Clinical House, the caretaker kept hens and on the surrounding golf course sheep grazed. At the beginning of the track leading to the Observatory there were stables and also a cottage where the famous professional golf champion J. H. Taylor lived; his two daughters worked in the Meteorological Office. A reminder that the peace of the place was temporarily shattered in the 1914–18 war was a bomb crater in the Observatory paddock. Another crater just outside was turned to useful purpose as a golf bunker.

One drawback associated with the site of the Observatory was the liability of the grounds to be flooded when the Thames overflowed its banks. One of the most serious floods occurred in 1928, when lives were lost at several places lower down the river. My own house near Kew Green was flooded to a depth of three feet, and amongst the many books which were damaged was an expensive new *Handbuch der Geophysik* which I had borrowed from the Observatory library. I persuaded the Superintendent to seek authority for it to be 'written off', and eventually the Finance Division of the then Air Ministry agreed, but warned that I should not let it occur again.

A description of the Observatory building given in the Kew Committee Report of 1859–60 includes the remark that 'the repose produced by its complete isolation is eminently favourable to scientific research'. This physical isolation of the building in the Old Deer Park did not, of course, mean that members of the staff lacked facilities for the exchange of ideas with other workers. Not only did the large number of visitors help in this respect, but every encouragement was given to the staff, particularly under Dr Whipple's direction, to attend meetings of the learned societies in London as well as the Monday evening scientific discussions of the Meteorological Office. Looking back after nearly 50 years since I first went to Kew Observatory, I think that the repose and the pleasant surroundings must have helped to make my 12 years service there the most productive and most enjoyable of my career.

Note : The photoheliograph, long unused, went to the Science Museum in 1927; the Robinson-Beckley cup anemograph was dismantled in 1929 and replaced by a pressure-tube anemograph; the necessary overlapping records were discussed in the 1931 *Observatories' Year Book*, pages 343–344. The photo-electrograph was originally set up by W. Thomson in 1861 with its boom projecting from the west side of the main observatory building (see Plate VIII); the siting at the adjacent Clinical House, which Scrase mentions here, occurred from 1915 to early 1940, when the instrument was returned to near the original site, where it still remains and records. The water-dropper was replaced by a radioactive (polonium) collector in 1931; there is also, from May 1958, a pen-record (valve voltmeter) from the Clinical House site. The John Welsh barometers are now in the Science Museum (see Plate X). The photobarograph is still in use. Of the magnetometers transferred to Eskdalemuir, the horizontal component and declination variographs are still recording.

The seismological work has, in the last few years, been entirely taken over by the Global Seismology Unit, Institute of Geological Sciences (IGS) (Natural Environment Research Council) Edinburgh. The Galitzin seismographs ceased operation at the end of 1964 and are now in the Science Museum; the Office has provided the IGS with microfilms of all available

seismograms from 1898 to 1964. Recording with the last seismograph at Kew short-period vertical) ceased at the end of March 1969 because the IGS then had another station providing coverage for southern England. The International Seismological Summary, which Scrase mentions as being established at Oxford, was given accommodation at Kew Observatory from 1947 to the end of 1967, when it disbanded on its function being taken over by the Global Seismology Unit, which then also took over the responsibility for publication of the seismological data for Eskdalemuir from 1968 onwards. The last issue of the *Seismological Bulletin* of the Meteorological Office was that for December 1967.

The full background story to the extra interest, from 1912, in the air pollution problem, which Scrase mentions, is given in the book by Sir Napier Shaw and J. S. Owens;[21] here it is mentioned that F. J. W. Whipple acted as scientific consultant to the Atmospheric Pollution Committee. Records of pollution from Kew and many other stations were collected and studied — the task is nowadays that of the Warren Spring Laboratory, Ministry of Technology. The original Owens hourly recorder at Kew, in routine use from 1 January 1921, was replaced on 1 January 1962 by a new recorder, designed at the Warren Spring Laboratory, in which the optical density of the smoke stains is measured by a photo-electric reflectometer. The gradual implementation of the 1956 Clean Air Act is shown by the annual maximum hourly value of smoke pollution at Kew falling, after 1964, below 1000 microgrammes per cubic metre of air for the first time since recording began. However, with the decrease of smoke, increasing attention has to be paid to the measurement of sulphur dioxide and the daily values at Kew have been notified to Warren Spring since January 1961.

L. JACOBS

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THE BRITISH RADIOSONDE : ITS DEBT TO KEW

By D. N. HARRISON, O.B.E.[1]

When I went to Kew Observatory as resident observer in December 1926, I was aware that L. H. G. Dines was calibrating meteorographs in a room at the south end of the Clinical House, having been in charge of this work since its transfer from his father W. H. Dines's home at Benson in 1923. My time at Kew was short, as I left for the Edinburgh Office in May 1927 and afterwards went on to Lerwick Observatory, but, as will be seen below, I was much concerned, from 1937 onwards, with the new radio methods being used for upper air measurements.

Crucial decisions. The development in other countries of radiosondes to replace the meteorograph during the 1920s is described in the *Handbook of meteorological instruments, Part II.*[2] The initiation of such a project in this country is recorded in the *Report of the Director of the Meteorological Office* for the year ending 31 March 1937, which states that 'the development work has been entrusted to the National Physical Laboratory, who are working in close collaboration with the Meteorological Office. Although the experimental stage has not been passed, very satisfactory progress towards the design of a suitable instrument has been made during the year'. It was decided that, in addition to measuring pressure (P), temperature (T) and humidity (U), radiosonde signals should be used to measure upper winds by direction-finding (DF), and my first contact with this work was in the autumn of 1937, when I was sent from the Instruments Branch by J. S. Dines, Superintendent, brother of L. H. G., to visit H. A. Thomas and H. G. Hopkins at the National Physical Laboratory (NPL) to be briefed on the requirements for DF sites.

After prospecting in the flat country of Essex with C. E. Britton of the Meteorological Office, Shoeburyness, I looked at sites on Salisbury Plain, where it was decided to set up a station at the Meteorological Office, School of Artillery, Larkhill.

Before the end of 1937 it was agreed that the instrumental work of the Office on the development of radio sounding should be based on Kew Observatory, the Upper Air Section, with L. H. G. Dines in charge, being combined with the Observatory work under F. J. W. Whipple, Superintendent. I had no further contact with the work until I went to Larkhill in February 1940.

The first British radiosonde was designed by H. A. Thomas;[3] the preliminary testing of sondes took place at Kew in December 1937, when the workshop was making calibration apparatus, and the first experimental ascent was made in April 1938. These sondes, known as the NPL Mark 1, were not successful, and were soon followed by Mk 2 and Mk 3. Meanwhile supplies of sondes and ground equipment were obtained from Professor V. Väisälä of Helsingfors, Finland, where A. J. Lander, of Kew, spent two weeks learning the technique. The first ascent with these sondes at Kew was made on 31 March 1939, and routine soundings began in the Isles of Scilly on 18 February 1940, under Lander's guidance. Sondes of the Bureau type were sent from France and, after trials at Kew under instruction from a French army sergeant, were used on routine ascents at Lerwick Observatory from 10 April 1940, again with initial help from Lander.

The supply of Väisälä and Bureau sondes was soon exhausted, on account of the war, and they were replaced by the NPL Mk 3.

The Kew sonde. After the Mk 3 had been used for a time at these stations and at Larkhill, the design was found to be faulty and a new sonde was developed by E. G. Dymond, from Edinburgh University, and H. Carmichael, from Cambridge, who had come to Kew towards the end of 1939. This, known as the Kew Mk 1, came into routine use in June 1941, replacing the NPL Mk. 3.[4] The NPL remained, however, responsible for the DF equipment and methods used by the Meteorological Office.

Kew was responsible for the supply, testing and calibration of all sondes. Up to the time of introduction of the Kew Mk 1 sonde, Kew made the meteorological units and commercial firms supplied the complete transmitter; subsequently, with further manufacture of parts, Kew's work was confined to dealing with the actual meteorological elements (for *P*, *T*, and *U*).

In addition to the work on sondes and calibration plant, certain important ancillary equipment was developed at Kew by Dines and Lander, notably the cone and gear for launching balloons in strong winds, 'unwinders', which allowed the long suspension string to be carried on a spool and unwound after the launch, and parachutes. There was also the invaluable radiosonde training machine due originally to E. H. Myer of Larkhill and developed and manufactured (from 1942) at Kew, which simulated mechanically the *P*, *T* and *U* changes normally experienced by a radiosonde in flight. Machines were issued to all stations for the training of operators. The work at Kew had by now increased greatly and there was a small very busy 'factory', a new Calibration House being built early in 1942; this work continued for the rest of the war and up to July 1946, when the staff and the work were transferred to the Instrument Branch at Harrow. (There was a similar transfer from Larkhill — see p.188 — in April 1947).

The development of upper wind observations by DF went on from 1938, first at Larkhill and later at other stations. This has already been described[5] and need not be dwelt upon here.

Growth of network. The network of stations was built up until by August 1942 Larkhill, Fazakerley (near Liverpool), Downham Market (near King's Lynn) and Lerwick were operating as combined radiosonde and radio-wind stations. Penzance replaced Scilly, with radiosonde only, in October 1940. The number of ascents was increased until by March 1944 the routine consisted of four a day.

This meant that the work of calibration was greatly increased, and in July 1942 a complete calibration plant, made at Kew, was installed at Larkhill, in order to ensure the supply of sondes in case of enemy action against Kew (which fortunately never occurred), and this was followed by a second one in January 1943.

It should be recorded that, during the war, valuable help was given by the United States Army Air Force, which ran radiosonde and radio-wind stations with their own equipment, and also provided staff at Larkhill for calibration and for routine soundings.

Technical changes. The Kew sonde has continued in use as the standard Meteorological Office sonde with only minor modifications (which will be mentioned later) until the present, but methods of reading have changed greatly. At first the audio frequency, from which P, T and U are found by means of calibration curves, was measured by comparison with a variable oscillator, the adjustment being made originally by matching the signals by audible beats, later by a 'magic eye', finally on a cathode-ray tube; much later still this manual method of observation was superseded by an automatic counter and recorder,[6] which gives a graphical record of the period, instead of the frequency.

The calibration work at Harrow was taken over by the Instrument Development Branch on its formation in 1948 (I came to Harrow in 1947 and became Head of the upper air section of this new Branch in 1948 and remained in the Branch until my retirement in 1962). A very effective mass-production plant was designed by H. L. Pace and H. E. Painter;[7] this, with modifications, is still in use.

Over the years certain changes have been made in Dymond's design. In 1946 the layout was redesigned for mass production;[8] this model became known as the Meteorological Office sonde Mk 2. Later, in order to lessen the risk of short-circuiting power lines, the half-wavelength aerial was replaced by one of a quarter-wavelength, a modification which required changes in the circuitry, and at the same time the stability of radio and audio frequencies against changes of temperature and battery voltages was improved; this modification, in 1950, was called the Mk 2B. An unforeseen result of this was that the third harmonic of the radiosonde signal interfered with the frequency-modulation radio-telephones used by some of the county police forces; to remedy this filters were incorporated into the radiosonde.

Army radar sets (GL3) superseded direction-finding for wind measurement after the war, and these proved to be so accurate that they could be used as a check on the heights above ground calculated from the radiosonde observations of *P*, *T* and *U*. A great deal of valuable information on pressure errors has been obtained in this way. Further information has been provided by 'twin' soundings, in which two sondes are carried by the same balloon. These methods are indirect and incomplete, but they are the only methods of any value for investigating the errors of the sondes, since there is no instrument of higher accuracy against which to compare the sonde in flight; tests on the ground do not give enough information. Much has thus been learnt about the variability of sondes one from another,[9] but very little about the systematic errors which are common to all sondes of one type at one time and the way in which these vary over long periods. The twin sounding method was extended at international trials in Switzerland, in which many different sondes were compared, sometimes half a dozen or more simultaneously being carried by the same bunch of balloons, but the difficulties of organization and technique and the unrepresentative nature of the conditions have meant that the results have been of little value.

Recent developments. The first radar sets employed manual following, that is to say, the operators kept the aerial pointing at the target by watching the reflected signal and recorded the indicated range, azimuth and elevation. Later, automatic following methods were introduced, and these enabled the rates of change of the co-ordinates to be computed automatically. The Meteorological Office, with the help of the Ministry of Supply (later Ministry of Aircraft Production), undertook in 1950 a project to apply radar pulse techniques to a combined sounding *(P, T, U)* and wind-measuring equipment to be known as the Radar Sonde Theodolite.[10] The development and basic design work of the radar sonde were carried out under F. E. Jones at the Telecommunications Research Establishment (now the Royal Radar Establishment) Malvern. Engineering and pre-production development was done by Mullard Research Laboratories. Much progress was made and a working prototype was produced in which all the results (*P*, *T* and *U*, and wind speed and direction) were recorded graphically or digitally; but the equipment, especially the airborne transponder, became so complicated and expensive that the project was abandoned in 1957. (The wind-finder portion was used for research purposes until the supply of transponders had been consumed.)

It was then decided that a fresh beginning should be made, and a new sonde and separate radar-wind equipment developed. This has been done. The new sonde, Mk 3, uses the same principle of audio-frequency-modulation as the Thomas sonde, but the frequencies are in the range $3\frac{1}{2}$–7 kc/s instead of 700–1000 c/s. The sensing elements are an improved aneroid capsule with greatly reduced temperature coefficient for pressure, giving significant results to at least 30 km, and our old friend gold-beater's skin for humidity, both actuating ferrite-cored inductors; but for temperature a fine tungsten-wire resistor, coiled as in a lamp filament and supported on a plastic frame, is used instead of the bimetal element. The time-constant and heating by

solar radiation are greatly reduced, and these wire elements have the additional advantage that they can be standardized and therefore need not be calibrated with their individual sondes, (as is necessary with the bimetal elements); the resistance varies from 950 ohms at 20°C to 500 ohms at – 100°C. The incorporation of a resistance element, especially one of such a comparatively low value, along with the inductors of the *P* and *U* units, has only been made possible by recent advances in transistor circuit design. The three units are switched into circuit by a battery-operated motor instead of a windmill, and the design of the switch allows the programme of readings to be changed easily.

It is expected that the new sonde will be in routine use in about two years' time.

Since the war, changes have been made in the upper air network and the stations are now at :

United Kingdom :	Aughton, Camborne, Crawley, Hemsby, Lerwick, Long Kesh, Shanwell, Stornoway.
Overseas :	Cyprus, Gan, Gibraltar, Malta, Masirah, Muharraq, Tobruk, and four Ocean Weather Ships on stations in the North Atlantic.

And so the work done at Kew Observatory 30 years ago, on the foundation laid by the NPL, still endures, and its influence can be traced through successive generations of radiosondes. We can confidently expect that the latest member of the family will prove to be the best.

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AIR–LAND INTERACTION, FOG, ATMOSPHERIC OPACITY — A MISCELLANY

By G. D. ROBINSON[1]

No one who has worked for any length of time at Kew Observatory regards the published record as an adequate source for a history of the ideas discussed and experiments conducted there: this article treats a miscellany of work, some of it recorded only in internal reports and in manuscript, and by some standards unsuccessful, but memorable enough to the participants and enlightening to them if not to the scientific world.

Investigations of fog and atmospheric opacity at Kew have for the most part been aimed at the specific and immediate problems. In the late 1920s M. G. Bennett, known for his work on railway signalling systems, spent some time at Kew perfecting an instrumental method for measurement of visibility. The resulting 'nephelometer'[2] operated on the extinction principle; obscuring screens were introduced in front of the eye until the distant light or object could not be seen. There is little documentation of this work, and no indication why the instrument was not adopted — it operated on the same principle as the Gold visibility meter[3] later put into general use in the Meteorological Office — though it lacked the continuous scale made possible by use of the optical wedge.

A few years later, systematic counts of Aitken nuclei and the large ion content of the air were begun at Kew. This was part of the comprehensive investigation of atmospheric electricity initiated by Sir George Simpson[4] and F. J. W. Whipple[5] and, amongst others, H. L. Wright took part in the measurements[6,7] during his term of service as Resident Observer. Some years later when working with the Naval Weather Service and faced with problems of visibility at sea, he remembered the Kew nucleus counts, and returned to the Observatory to make the analysis of land and coastal visibility observations,[8,9] work for which he was awarded the Buchan Prize of the Royal Meteorological Society.[10] He used these results to clarify the influence of Aitken nuclei and sea-salt nuclei on atmospheric opacity.[11,12,13]

The next attack on problems concerned with opacity was a more substantial effort in the mid-1950s. It resulted from a fusion of two lines of research — a study of airfield visibility problems,[14–17] particularly at the smoke-affected London/Heathrow Airport, six miles from Kew, and the study of ground-fog formation,[18] which had begun as an off-shoot of the energy-balance investigations to be described later. This investigation brought together the remarkable, if disparate, talents of A. J. Lander and K. H. Stewart; it has had an influence more pervasive than would be suspected by those who count success in terms of published pages and it was certainly a pleasure to be associated with it. A feature of this activity was the examination by Stewart of methods of determining the size-distribution of the particles responsible for atmospheric opacity in haze and fog. He made a thorough analysis of the shortcomings of impaction techniques standard at the time, and particularly of the possibilities of evaporation within the impactor, and began work on optical methods of size-distribution determination. The need for some kind of controlled foggy atmosphere became apparent, and Lander designed and built a well-insulated 3-metre cube with various experimental facilities, in which it proved remarkably difficult, but not impossible, to maintain a stable fog long enough to allow size-distribution determinations. Stewart worked on small-angle scattering methods within this chamber, and with optical and infra-red transmission in the open. Being of a thrifty disposition, and having no great faith in the routine utility of methods involving inversion of an integral equation, he scorned the temptation to spend money on expensive and fashionable equipment. The infra-red detector was a thermopile with filters, borrowed from the solar radiation programme. Two infra-red sources were respectively a domestic electric boiling ring, and a kettle in which water was being boiled. The kettle, in fact, served a dual

role in the investigation; it was also part of the humidifier of the fog chamber. The results of this work are recorded only in unpublished reports[19,20] to the Meteorological Research Committee; reports which repay study both of the methods used and the conclusions reached. They contain, amongst other things, an analysis of opacity in fogs at Kew in relation to size-distribution of the particles, stressing the importance of very small particles which make little contribution to the suspended mass, and the design of an efficient cascade impactor. There is a published discussion[21] of artificial fog clearance with suggestions for improvement of the hygroscopic-drop method of Houghton and Radford.[22]

Investigations of energy and momentum transfer at the surface at Kew grew naturally out of the radiation programme described by R. H. Collingbourne in the July 1969 issue of the *Meteorological Magazine:* the incident solar energy and the returning radiation from the ground were being measured; what happened to the balance of the energy absorbed by the ground ? The investigation at first followed well-established methods with measurements of the profiles of temperature, humidity and wind speed accompanying determination of the radiation balance at the surface; if there was any improvement over prior investigations of the same kind it was in the precision of the radiation measurements and, in the realization of the role of direct radiative heating and cooling of the lower layers of air. It was realized from the start that the site at Kew was far from ideal for comparison with theories of the boundary layer over an extensive uniform surface, but the investigators had in mind that such sites are exceptional and hoped to make a contribution of more general value, a hope which was not fully realized. Results are contained in internal reports; one published paper[23] summarizing the investigation deserves the attention of the student of the history of micrometeorology. Some observations taken immediately before the formation of ground fog are particularly interesting, with a near-linear wind profile and a temperature profile probably consistent with local radiative equilibrium.

At an early stage of this programme, it was decided to supplement the profile observations with measurement of the heat and momentum fluxes by the correlation methods which were being developed elsewhere, particularly in Australia by W. C. Swinbank and his colleagues. For this purpose experience in hot-wire anemometry was required, and this aspect was enthusiastically pursued by A. J. Lander who soon acquired skill in the construction of crossed-wire anemometers and built a small wind tunnel for calibration purposes in the laboratory still known as the Clinical House. Analogue computing aids were a common feature of similar laboratory investigations at the time, but it was decided not to employ these 'in the first instance', as it was felt that more insight would be gained into the nature of the processes involved if records of the fluctuations of temperature and the components of wind were available for inspection. This expectation was certainly borne out: the investigators associated with this programme over a period of about five years learnt a great deal about the lower layers of the atmosphere; the most memorable feature being a mistrust of the value of the correlation method for determination of fluxes, particularly of momentum, and particularly when measurements are made at only one point. The site of the field measurements was moved from the restricted area at Kew, first to a more open area

at Cardington, Bedfordshire, and then to a little-used airfield at Graveley, near Huntingdon, where a long fetch over flat treeless land was available for all wind directions. Many records were obtained. The scale of phenomena measured was set by the free period of the galvanometers used for recording: periods of 1/50 second, 1/10 second and 2 seconds were available, and records were taken for periods which allowed more than 2000 independent points to be measured. On most occasions independent methods of measuring heat or momentum flux were attempted, and the energy-balance method in use for the heat flux required a cloudless sky if the radiation measurements were to be made with sufficient accuracy. Waiting for such conditions was frustrating and the investigators often thought enviously of the climatic advantages of Australian workers in the field, but the envy was tempered when the day did arrive and work began in the green moderation of a perfect English summer day. N. E. Rider, A. J. Lander and H. E. Painter were associated with this work, and I am grateful to them for hard work which may well have greatly increased their appreciation of the complexity of the atmosphere but which brought them little immediate scientific recognition. Only one published paper commemorates this work and that is on a side issue,[24] but several unpublished reports were made.[25–29] So far as flux determination by the correlation method was concerned, the general experience was that this method (applied at a single sampling point) and the energy-balance method usually gave results which agreed within a factor of two for heat flux. Momentum flux, compared with the results of drag-plate techniques, was much less consistently determined, and spectral analysis often showed curious anomalies. A feature observed on more than one occasion was an apparent upward flux of momentum in the direction of the mean wind associated with the components of frequency a few cycles per hour. An attempt was being made, in collaboration with H. Charnock to operate over an extensive water surface (a reservoir at Kempton Park) when staff changes, and in particular the end of my own long stay at Kew, interrupted the work. It was not resumed: the pause allowed what would now be called a cost-benefit analysis, with discouraging conclusions.

It is interesting to note that at the same time as the Kew work was in progress at Cardington and Graveley, staff from the Meteorological Office Research Unit at the School of Agriculture, Cambridge, were investigating, using the same field sites, drag/profile relationships[30] and the factors affecting natural evaporation from grass.[31]

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DEVELOPMENT OF ROCKET AND SATELLITE EXPERIMENTS AT KEW OBSERVATORY, 1959–61

By K. H. STEWART

Kew has been the home of many pioneering investigations. One of the most recent began on 1 October 1959 when D. E. Miller arrived to study, in consultation with the Superintendent (K. H. Stewart), the feasibility of measuring ozone from an artificial earth-satellite. The United States generously offered to build and launch satellites carrying experiments designed and made in other countries, and the Meteorological Office was anxious to provide one of the experiments in an early satellite of what became the ARIEL series. Dr G. D. Robinson, Deputy Director (Physical Research) had been a member of the party which accompanied Professor H. S. W. Massey to the U.S.A. in June 1959, to negotiate the agreement by which British experiments would be mounted on these American-launched satellites, and it resulted from this that D. E. Miller was sent to Kew and became the first member of the High Atmosphere Branch which was officially established, at the Meteorological Office, Harrow, at the end of February 1960.

The early work at Kew covered a wide range of subjects from the properties of satellite orbits to the design of filter and prism systems and the practical details of data storage and telemetry. It soon became clear that measurements of useful accuracy and with a satisfactory geographical coverage ought to be practicable from the rather simple satellite that was envisaged, and by early 1960 definite plans for the satellite experiment were put forward.

The principle of the experiment was to measure the attenuation of ultra-violet sunlight by the ozone in the atmosphere at times when the satellite was just entering or leaving the earth's shadow, and the sun's rays had to pass tangentially through the atmosphere to reach the satellite. The crucial point of the design was the devising of sensor systems that would measure light of the selected wavelengths. In the end two systems were chosen, one very simple, relying on the inherent photo-electric response of a suitable metal (thorium) to produce a signal from a broad band of wave-lengths in the ozone absorption region, and the other more elaborate, using a prism spectrometer which would scan the sun's ultra-violet spectrum as the satellite rotated. In order to test and measure the components of these systems and to calibrate the complete units when made, an ultra-violet monochromator was obtained, together with various other ultra-violet sources and a collection of electronic measuring equipment, and was set up, for lack of another suitable darkroom, inside the 'fog chamber' that had been built a few years earlier in the wooden hut previously used for radiosonde calibrations.

The group at Kew, now under the new High Atmosphere Branch, expanded rapidly during 1960 to include K. H. Stewart, G. P. Carruthers, D. G. James and one or two assistants, and work went ahead on many fronts at once. An essential preliminary to the satellite experiment was the testing of equipment (and of the operation of the experiment generally) in a rocket flight, and the most pressing task became the construction and testing of sensor

units and electronics for this flight. The spectrometer units were designed and assembled at Kew, the mechanical parts being made in the workshops at Harrow; the 'broad band' units were entirely made at Kew, using the staff and resources of its workshop. Assembly, testing and calibration were done in the old 'calibration' hut, and many relics of earlier work at Kew were pressed into service to fill gaps in the equipment available. In particular, an old brass dip-circle which originally came from Falmouth became the main mounting device for the calibration of spectrometers at different angles of incidence. Besides this practical work, much planning went on for the incorporation of the experiments into the satellite, and elaborate studies were made of mathematical methods of handling the data to be expected so as to derive the ozone concentrations, not an easy matter, since the quantities observed would depend on ozone amounts integrated over large regions of the atmosphere both vertically and horizontally.

By early 1961 construction of the rocket equipment was more or less complete and a series of visits to the Royal Aircraft Establishment (RAE), Farnborough, began, for the final testing of equipment and its assembly and testing in the instrument bay of the rocket. In these last months at Kew the group was joined by D. W. S. Limbert and D. S. Hamilton. In July, as the Meteorological Office's first rocket experiment left Kew for the RAE and its long journey to Australia and thence into the upper atmosphere, the High Atmosphere Research Unit moved from its nursery at Kew to a new home at Bracknell.

This first SKYLARK rocket was launched in November 1961 and was technically successful, though the information yielded was not very precise. It has been followed (to date) by seven further SKYLARKS carrying equipment of gradually improving accuracy and reliability, which has given good measurements of ozone at heights between 40 and 80 km.[1] An unexpected by-product has been the measurement of the large amount of dust injected into the atmosphere by the eruption of Mount Agung (Bali) in 1963.[2] The satellite version of the experiment was launched in ARIEL 2 in March 1964, and operated with fair success over the next six months.[3] In more recent years the same basic technique has been used for the measurement of molecular oxygen at greater heights, 100–250 km, both from rockets[4] and from the ARIEL 3 satellite.[5,6]

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REVIEWS

Die Wissenschaft vom Wetter, by H. Reuter. 185 mm × 120 mm, pp. viii + 146, *illus.*, Springer-Verlag, 1 Berlin 33, Heidelberger Platz 3, Berlin-West, 1968. Price: DM 7.80.

This little book is one of a series entitled *Comprehensible science*. The author is Professor of Theoretical Meteorology at the University of Vienna. He writes in the preface that his aim has been to bring the results of research by meteorologists to a wider circle of readers in exact but generally comprehensible form with special attention to progress since the publication before the last war in the same series of von Ficker's book *Wetter and Wetterentwickelung*.

The book provides a very readable non-mathematical account of many aspects of meteorology. The main subjects covered are the general structure of the atmosphere, radiation, general circulation and jet streams, cloud and precipitation, hydrological cycles, atmospheric circulations from tornadoes to large-scale pressure systems, present methods of observation (satellite cloud pictures, radar) and weather forecasting. A notable absentee is atmospheric diffusion. Particular care, as is proper to a writer in Vienna, is given to a good clear account of the sources of the energy of the wind. The account of numerical forecasting is not good. The methods used in most countires based on the solution of the equations of motion of a model atmosphere adjusted to agree at certain levels with current observations are not mentioned; the author merely says that numerical forecasting depends in principle on the determination of an 'influence function' at each point of the grid.

The reproduction of the diagrams and half-tones, notably the satellite cloud photographs, is excellent.

The book is written in a simple clear style and would give good reading practice in German to English-speaking meteorologists.

G. A. BULL

Der Aufbau der Erdatmosphäre, by H. Faust. 235 mm × 165 mm, pp. viii + 307, *illus.*, Vieweg and Sohn, Brunswick, 1968. Price: DM 56 (112*s.*).

Most books of meteorology, apart from a brief mention of noctilucent clouds, meteor trails and auroral displays, confine their attention to the troposphere and the stratosphere up to about 30 km. There are, of course, plenty of books about the ionosphere and magnetosphere, but as far as I know this is the first fairly comprehensive treatment of the atmosphere as a whole. In this ambitious attempt the author, writing in a very individual way, has made a notable and very interesting contribution to meteorological literature.

A main theme running through the book is the layered nature of the atmosphere starting from the peplosphere (friction layer) and the troposphere, into the stratosphere, mesosphere and ionosphere. He refers repeatedly to the importance of 'null layers', i.e. layers through which the meridional gradient of temperature changes sign. The lowest of these is at about 10 km

where the normal polewards fall of temperature of the troposphere gives way in some latitudes to a rise. He claims that in the mean the vertical velocity changes sign at a null layer but it is not easy to see quite what importance this bestows on the layer. His other claim that the west winds are super-geostrophic at this null layer has as a consequence a flux of mass towards south, thereby providing a mechanism for the maintenance of the subtropical belt of high pressure against the dissipating effect of friction. He recognizes another null layer at the level of the mesospheric wind maximum at about 60 km, and, in the winter hemisphere, he claims that the level of minimum west wind between 20 and 25 km also represents a null layer. This, he says, represents a separating layer (Trennschicht) between the circulation arising from the heat supply at the earth's surface and that arising from the heat supply at the ozonosphere. However, other workers do not recognize a change in sign of the vertical motion at this level. This 'null layer' concept of Faust does not in the ten or so years since it was put forward seem to have received much attention by meteorologists outside Germany.

Despite this stress on null layers (some of which are explicitly termed separating layers), Faust claims that we must bear in mind the possible interactions of the various layers of the atmosphere. For example, if changes in the ozonospheric circulation due to variations in the ultra-violet part of the solar radiation affect the tropospheric circulation, then this will have important implications in long-range forecasting. Despite his concept of a separating layer at 20–25 km Faust presents the possibility of a frictional coupling which would produce such an interaction.

To go back to the beginning, the treatment of tropospheric conditions (about the first third of the book) is fairly standard but enlivened by a markedly individual approach which here and there pulls one up sharply. Such as, for example, when he says that the friction layer prevents cloud base falling to the surface in bad weather and that near fronts the friction layer is destroyed by the turbulent motions !

The next third of the book deals with the wind and temperature distribution from the tropopause to the limit of the homosphere, i.e. the region with a nearly constant composition which he puts at about 100 km. He describes how measurements from rocket ascents at Ascension from October 1962 to early 1965 indicate decreasing easterly components in the winds at levels above 40 km. It appears from these measurements that in the upper part of the ozonosphere the 26-monthly oscillation of the zonal wind is no longer present. Several other very interesting mesospheric circulations revealed by these rocket soundings, are also discussed.

This section of the book ends with an ambitious chapter on 'The homosphere as a whole', in which he discusses the inherent predictability of atmospheric processes and presents the views of some meteorologists that the large-scale variations in weather cannot be understood without taking account of what is happening in the greater part of the homosphere — up to about 70 km anyway.

The book finishes with an account of those regions in which ions are present in significant numbers so that magnetodynamical terms have to be taken account of in the equations of motion.

In the final chapter he discusses conditions at the levels where space craft operate, speculating on the kind of space-weather briefing they may require to avoid hazards such as proton storms.

This monograph is not written primarily for meteorologists, but for geophysicists who may wish to gain a picture of the atmosphere as a whole. It is very well produced and with one or two exceptions the diagrams are clear and helpful. References to the literature (listed under authors' names) are abundant (438 in all) but naturally enough well over half are to writings in German.

There is one misprint in this list of references (which will greatly amuse the author concerned); E. Gold's classic paper of 1909 on the stratosphere is given the date 1009 !

M. K. MILES

Seasonable weather, by L. P. Smith. 250 mm × 190 mm, pp. 146, *illus.*, George Allen and Unwin Ltd, Park Lane, Hemel Hempstead, Herts., 1968. Price: 50*s*.

A brave man is he who dares to unravel the vagaries of our British climate ! Certainly there is no one better qualified for this unenviable, yet fascinating task than Mr Smith, whose earlier book *Weatherwise gardening* is unique and whose wide experience in the field of agrometeorology needs no mention.

Seasonable weather, comprising 146 pages and numerous plates, is virtually two books in one. With Mr Smith's own illuminating survey of our last century of weather is incorporated a reprint of a superb series of photographs from an earlier book, *Weatherwise*, by the late Mr J. H. Willis. These span a period of no less than 29 years and faithfully record the state of growth on fixed annual dates of the same clumps of snowdrops and daffodils and the same branches of chestnut and beech. It is to someone's credit that this excellent opportunity has been taken to republish them.

Mr Smith examines methodically the behaviour of our weather during the hundred years 1850–1949. Detailed records of this period are condensed into simple tables as each season is 'cross-examined' in its turn. Subsequently the weather for the years 1950–67 is first described and then compared with the general trends of the previous century. From this, the outstanding feature is the almost continuous series of warm autumns since the last war (and 1968 has proved no exception). Generally, however, there is confirmation, if any were needed, of our weather's sheer inconsistency and one begins to wonder if, indeed, there is such a thing in these islands as a normal season.

The investigation into certain weather lore — indeed the whole book — is full of interest and reasoned interpretations. Perhaps, however, the most heartening single fact to emerge from *Seasonable weather* is its defence of our much maligned climate '. . . it does not run to insufferable excesses . . . most of all a good climate for growing things . . . the countryside is always green'. How very true !

E. J. GILBERT

CORRECTION

Meteorological Magazine, October 1951, p. 297. The date for the transit of Venus should read June 3, 1769.

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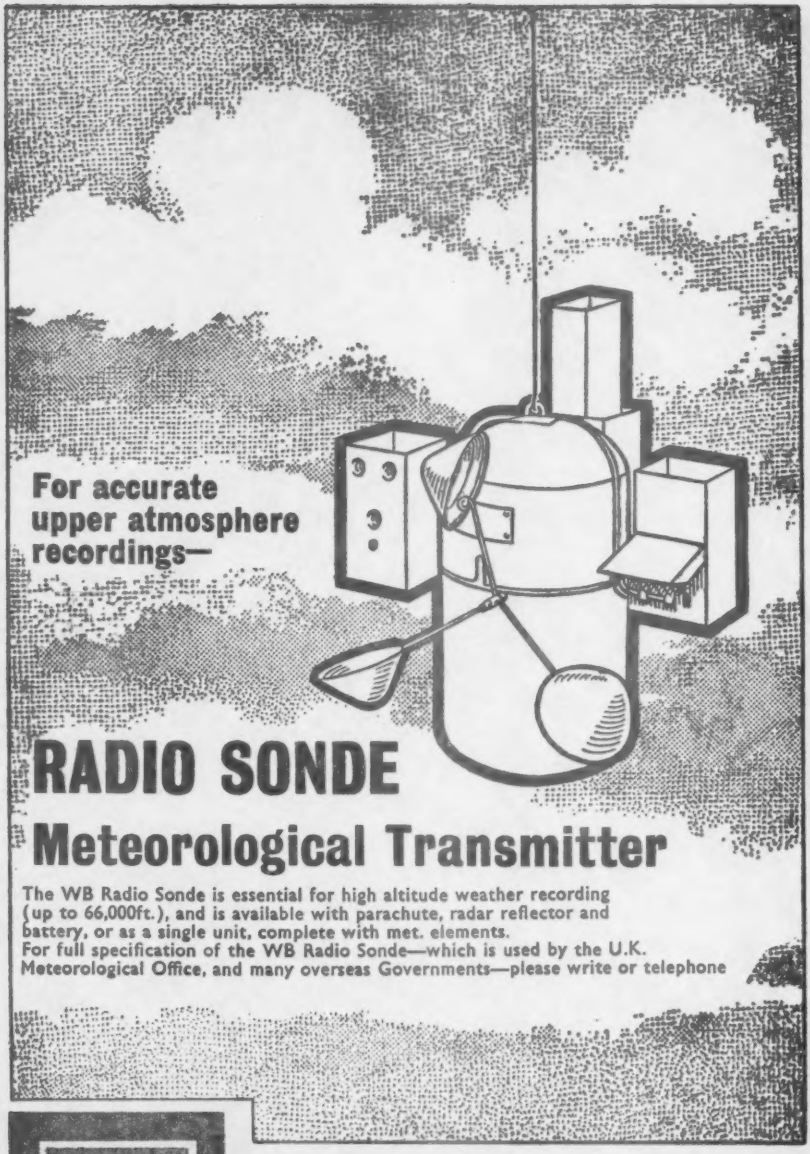

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NOTICES

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Printed in England by The Bourne Press, Bournemouth, Hants.

and published by

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3*s.* 6*d.* monthly **Annual subscription £2 7*s.* including postage**

Dd. 152073 K16 6/69

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